Design & Consultancy
for natural and
built assets

WHITE PAPER

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February 7, 2019

HOMESTAKE MINING COMPANY OF CALIFORNIA

Grants Reclamation Project

Evaluation of Water Quality in Regard to Site Background Standards at the Grants Reclamation Project

September 2018

90041265

Meeting Agenda

- Introductions, safety share
- Meeting Objectives
- Overview of White Paper

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When you do the same tasks many times, **AWARENESS OF THE MOMENT** may slip away.

Shortcuts in procedures introduce new **risks** into a routine **task**

Routine tasks have different **hazards and risks** every day

'EXPERIENCE MAKES YOU INVULNERABLE' **IS A FALSE BELIEF**

Complacency, pressure to work fast and lack of awareness may increase the chance of injuries

What can I do?

1. Consider every task as a new task
2. TRACK before every task
3. Don't shortcut procedures
4. Maintain a safe workplace by following established protocols and procedures
5. When on site, have daily safety meetings to discuss changes and potential hazards
6. Use "If not me then who", and address your colleague when you see unsafe behavior

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HMC Grants Mill site background

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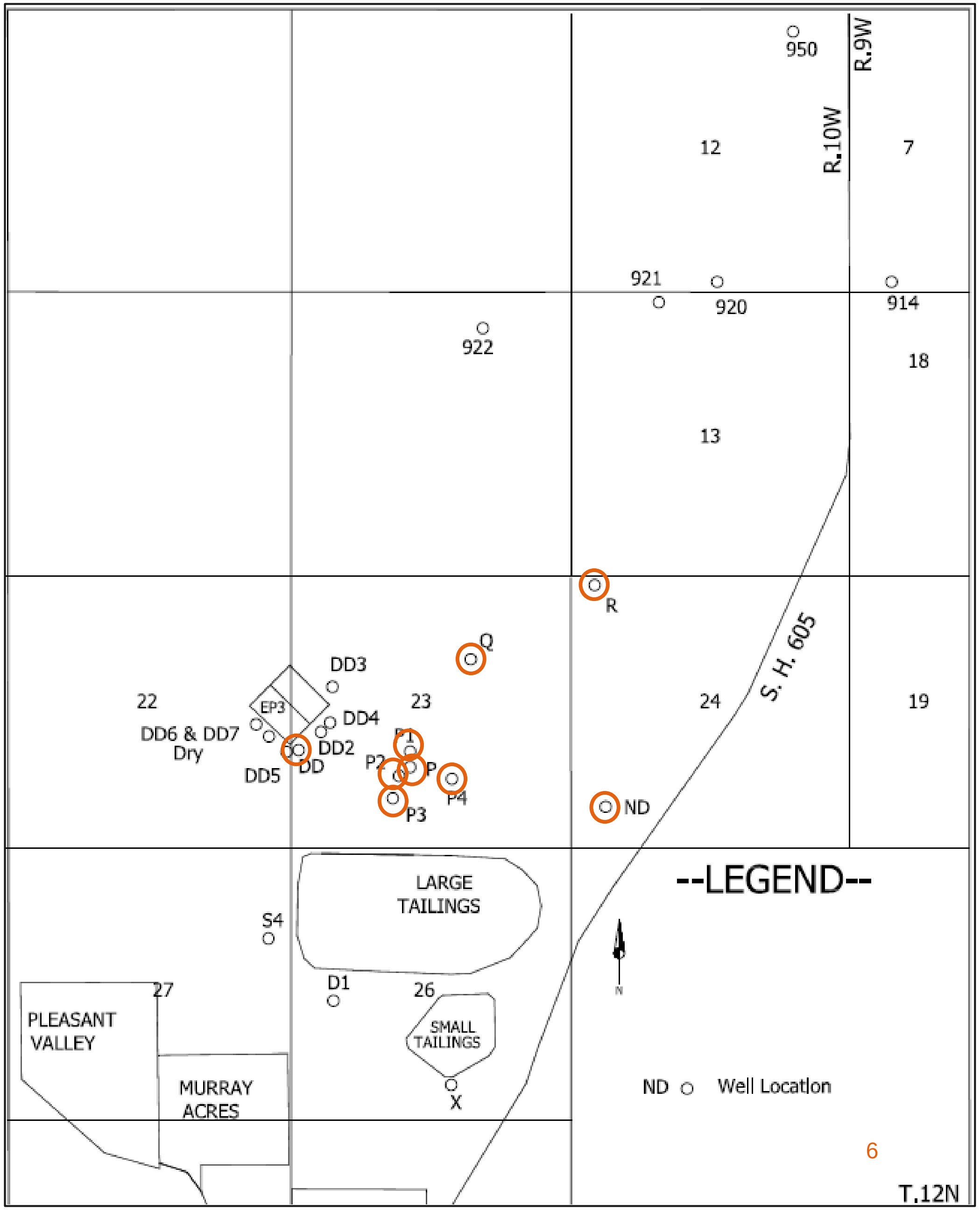
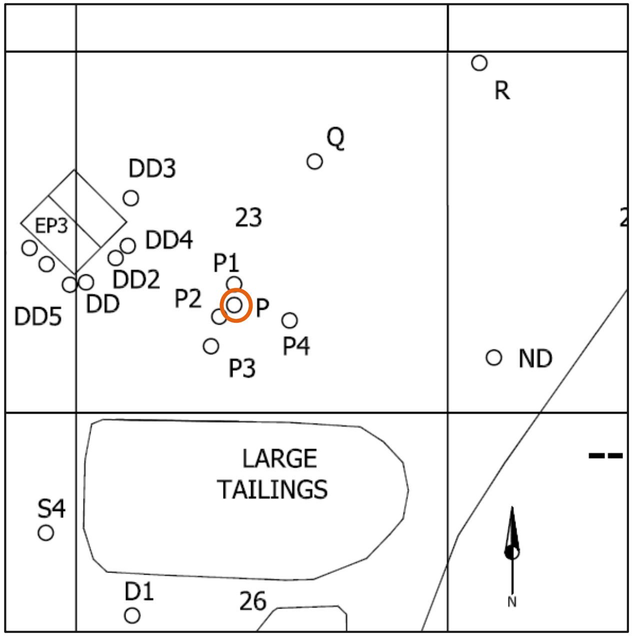
Well locations

- Wells used in at least one background dataset



1989 Corrective Action Program

- Background (upgradient) alluvial well P
- NRC identified well P as "most representative of background water quality" (NRC 1989); other wells were also evaluated (DD, Q, and R) but data was not used
- December 1988, January, February 1989 data for well P were used
  – 1 well, average these three data points



1989 CAP GWPS	
Constituent	**Conc. (mg/L)**
Chromium	0.06
Molybdenum	0.03
Selenium	0.10
Vanadium	0.02
Uranium	0.04
Thorium-230	0.03
Radium-226 + 228	5.0 pCi/L

NRC. 1989. Letter to file title "Establishment of Ground-Water Protection Standards," from Gary Konwinski, NRC PM, ADAMS Accession #ML060400039.

2001 Re-evaluation of Background

- Statistical evaluation by ERG
- 1976-1998 data set used for wells DD, ND, P, P1, P2, P3, P4, Q, and R
  - DD, P, Q, R (since 1976)
  - ND (1983)
  - P1, P2 (1992)
  - P3, P4 (1998)
- 2005 NMED request:
  base background standards on the last ten years of data since older data "would not be representative of the water quality that moves on site" (NMED 2005)

Figure by Hydro-Engineering, 2018.

NMED. 2005. Memorandum from William C. Olson to Sai Appaji titled New Mexico Environment Department comments on proposed ground water background concentrations.

2006 Re-Evaluation of Alluvial Background for Updated Standards, License SUA-1471

- Groundwater sampled at nine alluvial background wells: DD, ND, P, P1, P2, P3, P4, Q, R

- 9 wells, 124 data points, 1995-2004

Figure by Hydro-Engineering, 2018.

2006 Re-Evaluation of Alluvial Background for Updated Standards, License SUA-1471

- Statistical evaluation performed by ERG:
  - Outliers removed (max. values >3x the next highest value)
  - Non-detects set at DL/2
  - 95th percentile used to determine background value for U
  - Arcadis evaluated this in 2016
    - Used EPA's ProUCL software and updated standard statistical methods

- Uranium background detailed as the proposed GWPS for uranium in License Amendment #39 (NRC 2006)

  - GWPSs for the site are a combination of NRC standards, EPA standards, NM standards, and site background standards depending upon constituent

- GWPSs (including background uranium concentration (0.16 mg/L)) accepted by NRC, and agreed to by EPA and NMED (EPA 2006 and NMED 2005)

Grants Site Groundwater Protection Standards, License SUA-1471, DP-200

Constituents [a]	Alluvial	Chinle Mixing Zone	Upper Chinle Non-Mixing Zone	Middle Chinle Non-Mixing Zone	Lower Chinle Non-Mixing Zone
Selenium (mg/L)	**0.32**	**0.14**	**0.06**	**0.07**	**0.32**
Uranium (mg/L)	**0.16**	**0.18**	**0.09**	**0.07**	0.03[b]
Molybdenum (mg/L)	0.1[b]	**0.1**	0.1[b]	0.1[b]	0.1[b]
Sulfate (mg/L)	**1,500**	**1,750**	**914**	**857**	**2,000**
Chloride (mg/L)	250[b]	250[b]	**412**	250[b]	**634**
TDS (mg/L)	**2,734**	**3,140**	**2,010**	**1,560**	**4,140**
Nitrate (mg/L)	**12**	**15**	*	*	*
Vanadium (mg/L)	0.02[b]	0.01[b]	0.01[b]	*	*
Thorium-230 (pCi/L)	0.3	*	*	*	*
Ra-226 + Ra-228 (pCi/L)	5	*	*	*	*

Notes:

[a] **Bold shaded** values indicate GWPS was based on a site-specific statistically-based value.

[b] GWPS based on non-statistical value (EPA established values).

* Site standards were not proposed for the constituents in the indicated aquifer.

These standards are also the Corrective Action Program remedial standards.

White Paper

White paper contents

- Historical site and regional data
- Data from 2016 USGS groundwater sampling event on behalf of EPA
- Data from Arcadis 2018 borehole investigation:
  - Lithological logging
  - Sampling and chemical analysis
  - Down-hole geophysics

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Grants Reclamation Project

HOMESTAKE

Evaluation of Water Quality in Regard to Site Background Standards at the Grants Reclamation Project

September 2018

San Mateo Creek Basin Geology

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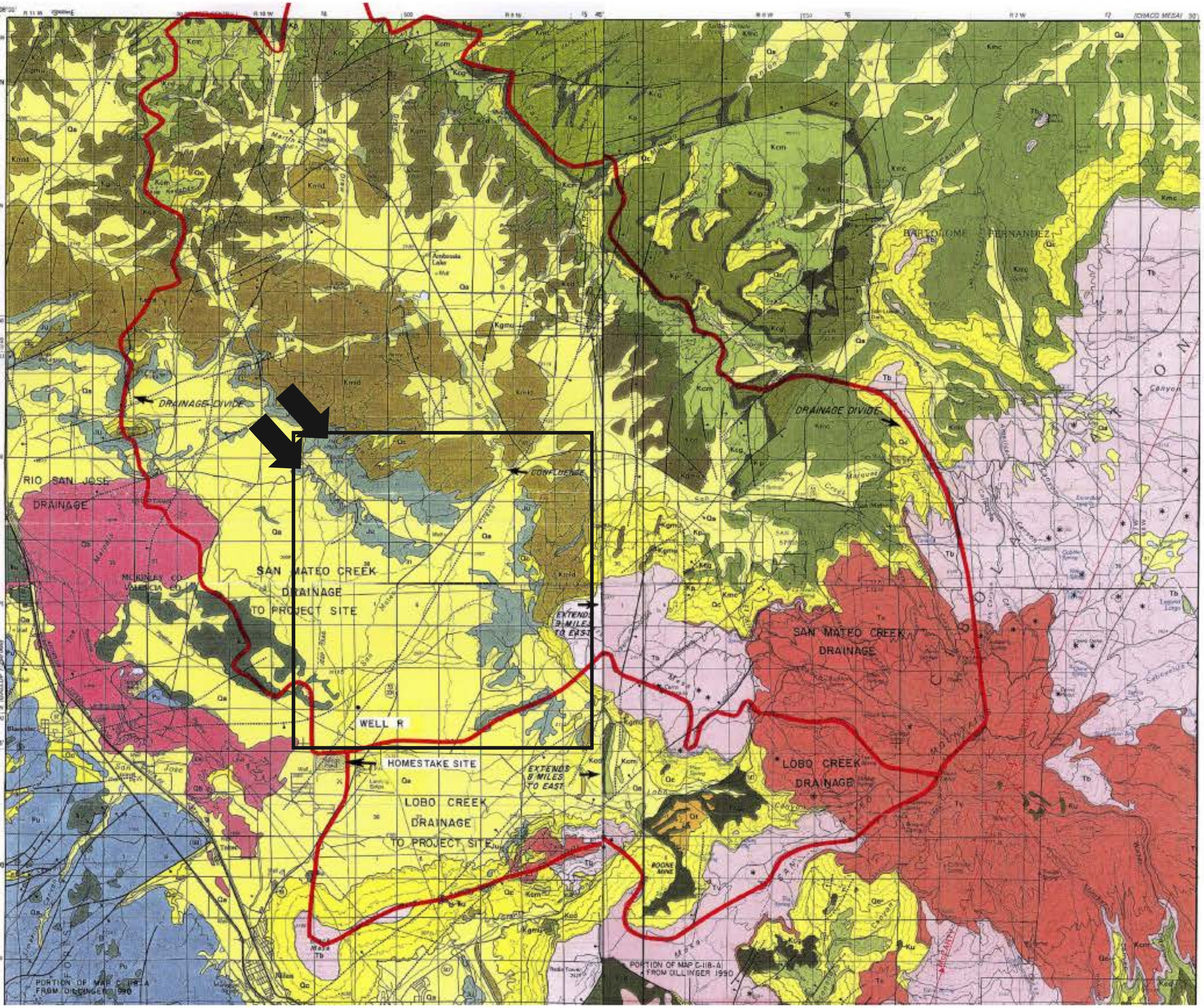
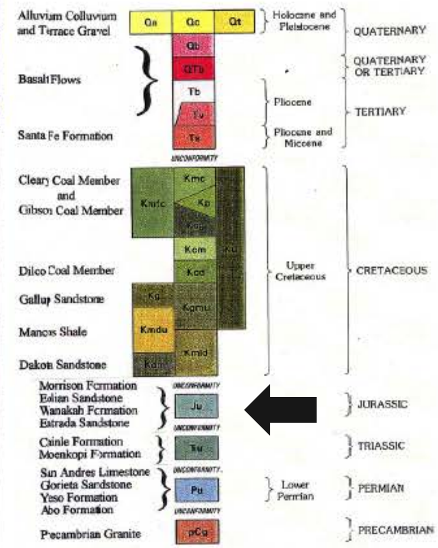


LEGENDS: Correlation of Map Units



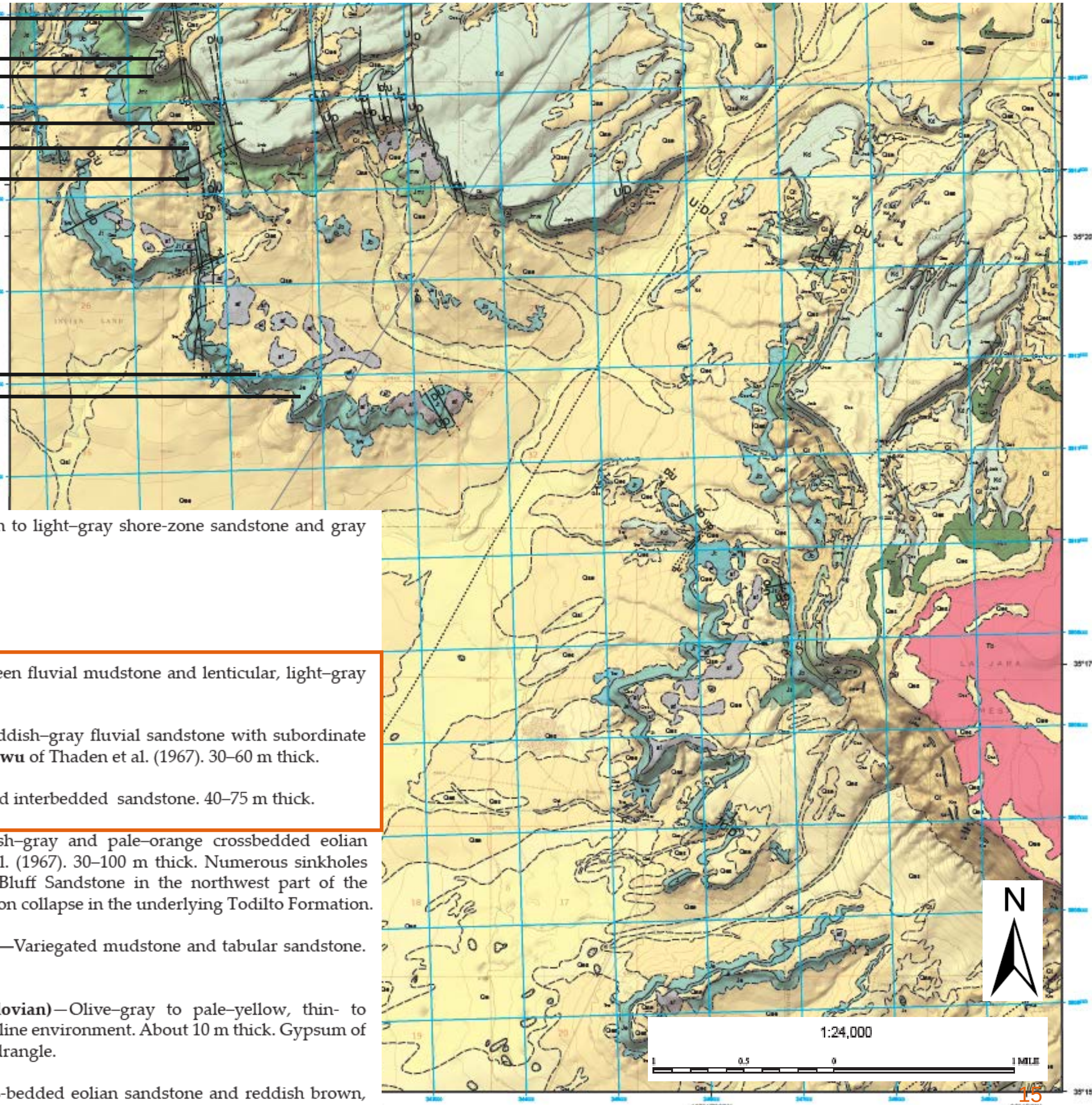
Source:
Dillinger, J.K., 1990, Geologic map of the Grants 30' x 60' quadrangle, west-central New Mexico: U.S. Geological Survey, Coal Investigation Map C-118-A, scale 1:100,000.

GRANTS RECLAMATION PROJECT

Updated Corrective Action Program (CAP)

FIGURE 3.1-1
BEDROCK GEOLOGY

San Mateo Creek Basin Geology



Kd — **Dakota Sandstone (Cenomanian)**—Yellowish–brown to light–gray shore-zone sandstone and gray mudstone. About 25 m thick.

JURASSIC

Morrison Formation (Kimmeridgian and Tithonian)

Jmb — **Brushy Basin Member**—Grayish–green to bluish green fluvial mudstone and lenticular, light–gray sandstone. 10–40 m thick.

Jmw — **Westwater Canyon Member**—Light–yellowish to reddish–gray fluvial sandstone with subordinate greenish-gray mudstone. Includes units **Jmwl** and **Jmwu** of Thaden et al. (1967). 30–60 m thick.

Jmr — **Recapture Member**—Variegated fluvial mudstone and interbedded sandstone. 40–75 m thick.

Jb — **Bluff Sandstone (Oxfordian)**—Light-gray, yellowish-gray and pale-orange crossbedded eolian sandstone. Includes units **Jb** and **Jsa** of Thaden et al. (1967). 30–100 m thick. Numerous sinkholes (small circular areas on map) are exposed in the Bluff Sandstone in the northwest part of the quadrangle. These are presumably the result of solution collapse in the underlying Todilto Formation.

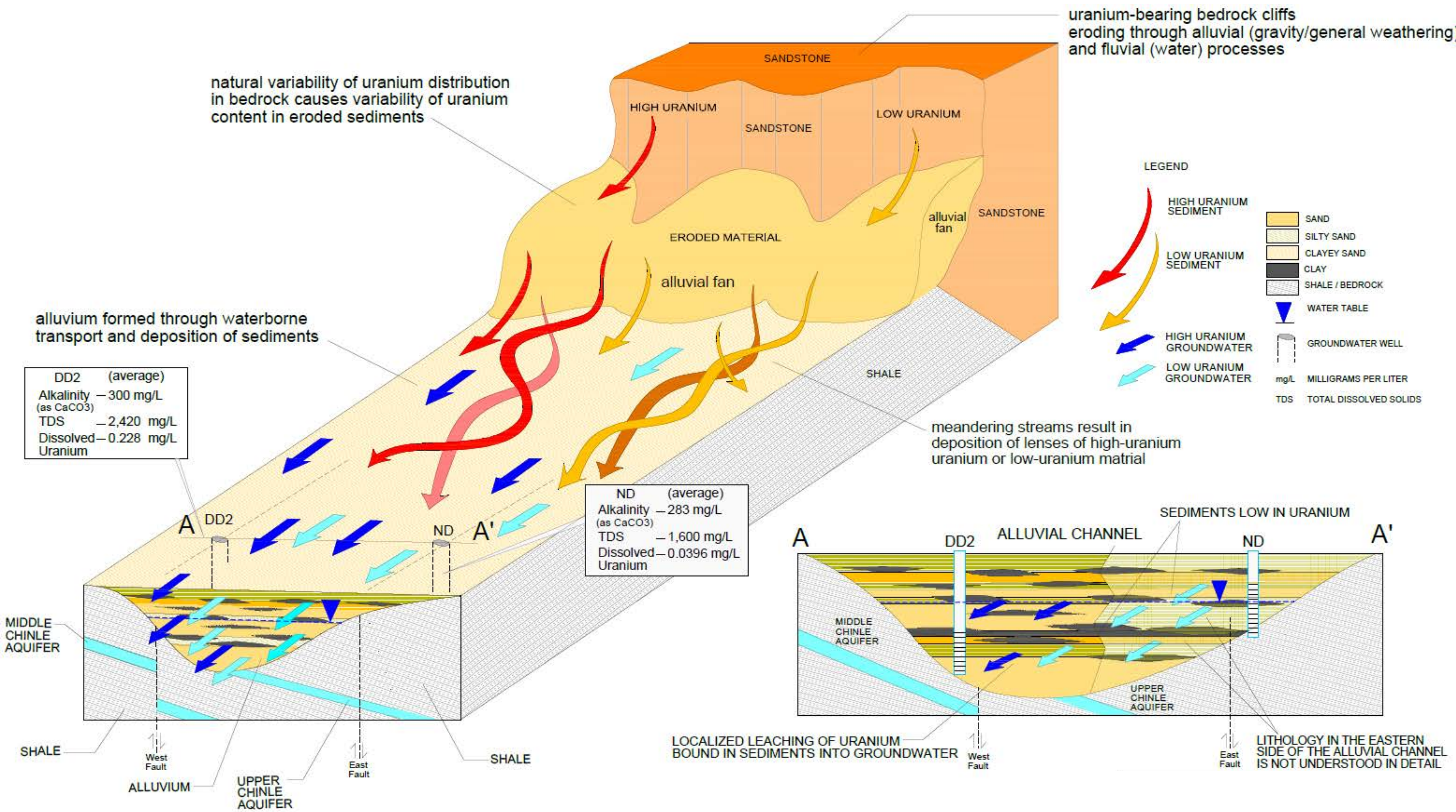
Js — **Summerville Formation (Callovian and Oxfordian)**—Variegated mudstone and tabular sandstone. 40–50 m thick.

Jt — **Todilto Formation, Luciano Mesa Member (Callovian)**—Olive–gray to pale–yellow, thin- to thick-bedded limestone deposited in a lacustrine or saline environment. About 10 m thick. Gypsum of the Tonque Arroyo Member is not present in the quadrangle.

Je — **Entrada Sandstone (Callovian)**—Light–brown, cross-bedded eolian sandstone and reddish brown, tabular-bedded siltstone. About 50 m thick. Includes units **Jem** and **Jeu** of Thaden et al. (1967).

White paper conceptual site model

- Source of alluvium = weathering and erosion of exposed bedrock formations over hundreds to thousands of years.
- Eroded sediments were transported/deposited by a meandering stream of varying velocity, resulting in alternating clay, silt, sand, and gravel layers.
- Concentration of uranium in the deposited sediments depends on both erosional and depositional environment:
  - High uranium bedrock units would weather into high uranium alluvium
  - Fine-gained sediments = higher uranium = high uranium alluvium
- Regional groundwater recharge varies across basin; groundwater along the east derived from lower-solute, low-uranium snowmelt from Mount Taylor.
- Uranium has leached from silt/clay-rich layers in the alluvial sequence in response to groundwater geochemistry (elevated alkalinity and TDS), resulting in groundwater containing variable natural uranium concentrations with depth and across the alluvial channel.

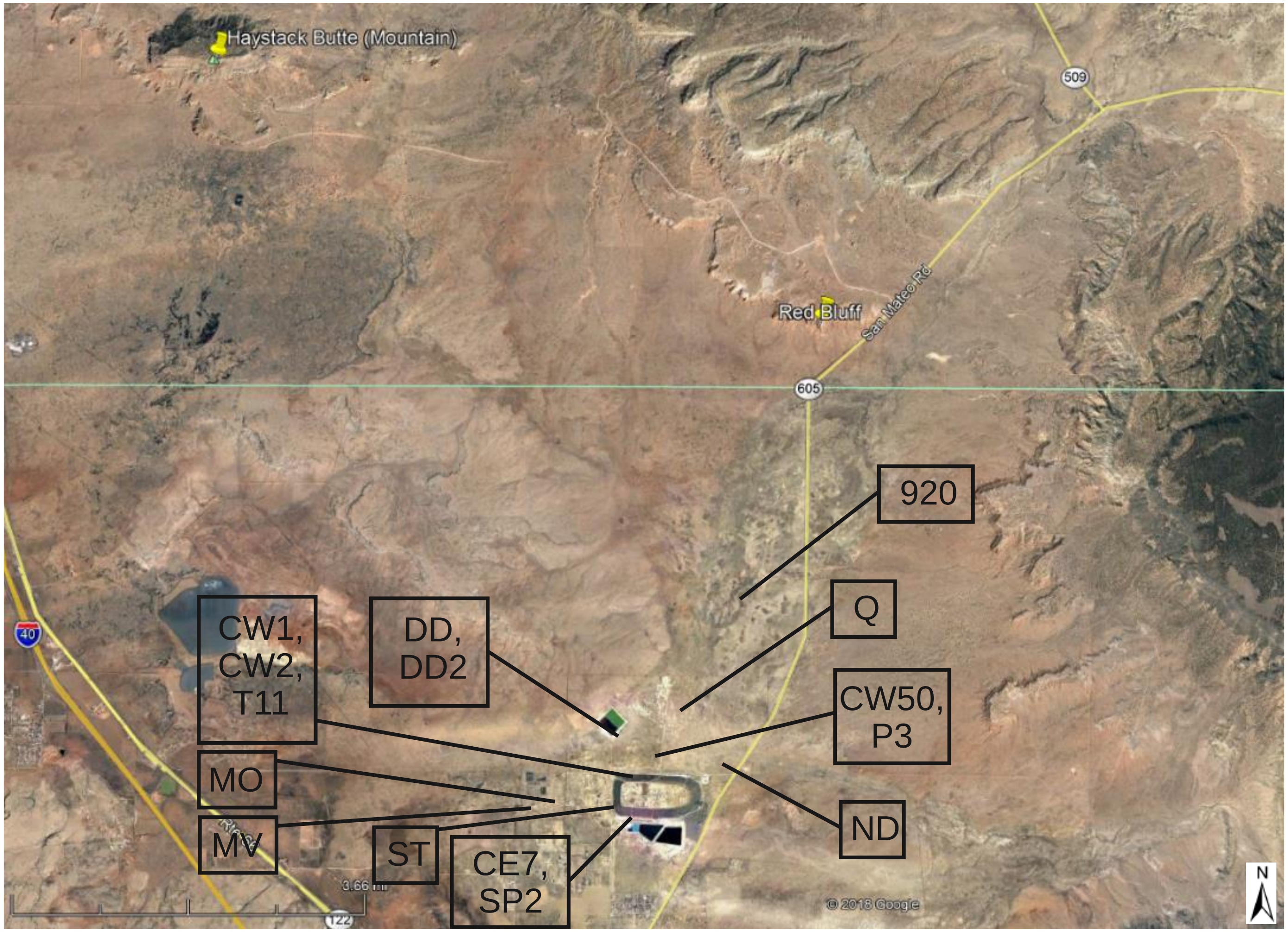


Potassium-thorium plots support different alluvial sediment origin from east to west

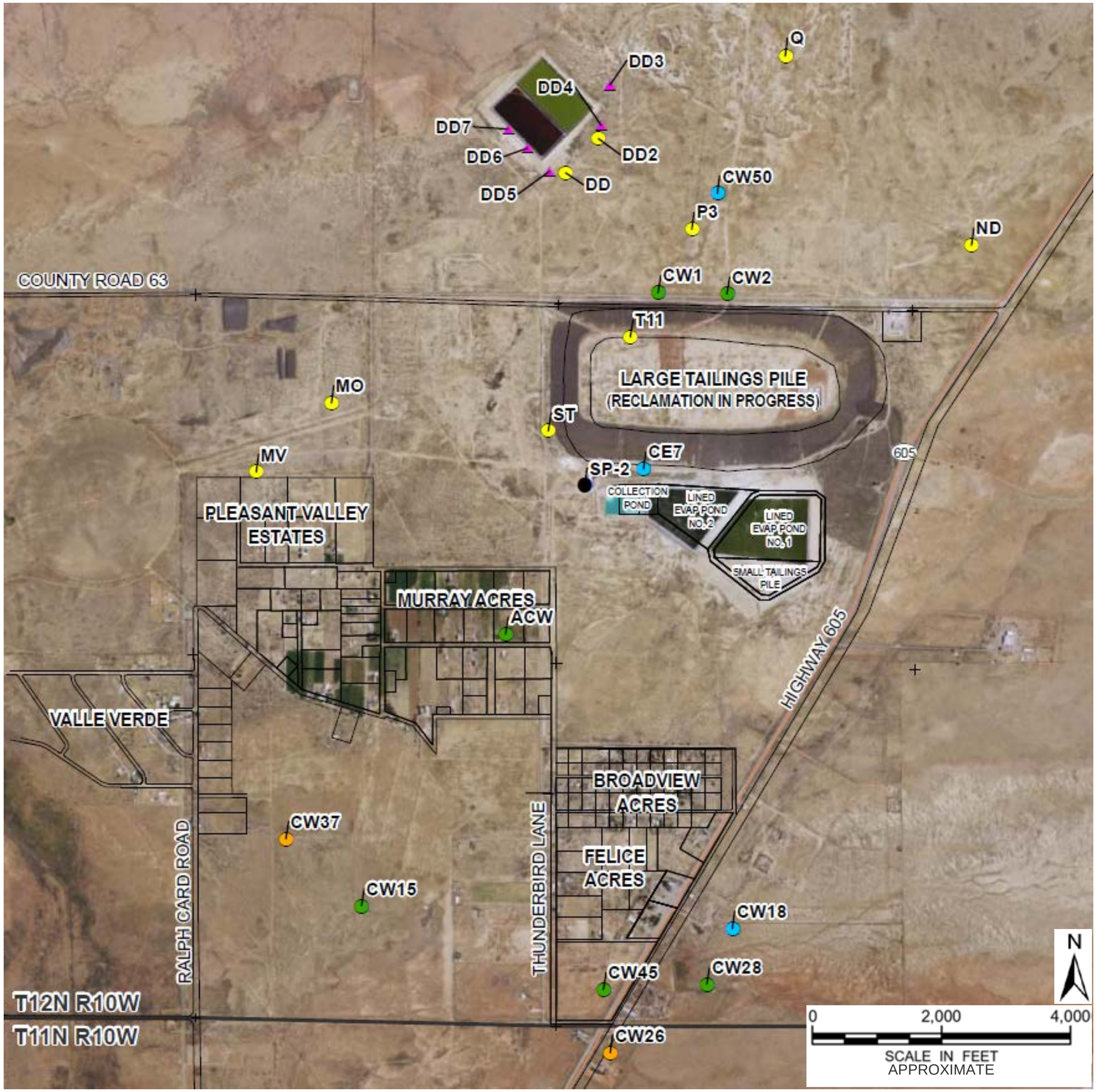
White paper conclusions

- High uranium in the unsaturated zone shows that uranium is present in unaffected alluvial sedimentary material
- High uranium in samples protected from outside water by clay show that the uranium is not due to groundwater contact or surface water infiltration
- Mineralogy/lithology local to a well influences water chemistry
- Alluvial lithology and geologic cross section of the alluvial valley has been revised
- Upgradient alluvial background wells are not affected by LTP
- Upgradient background uranium and selenium concentrations in groundwater are highly variable

2016 USGS Sampling Event (select wells shown)



2016 USGS Sampling Event (select wells shown)

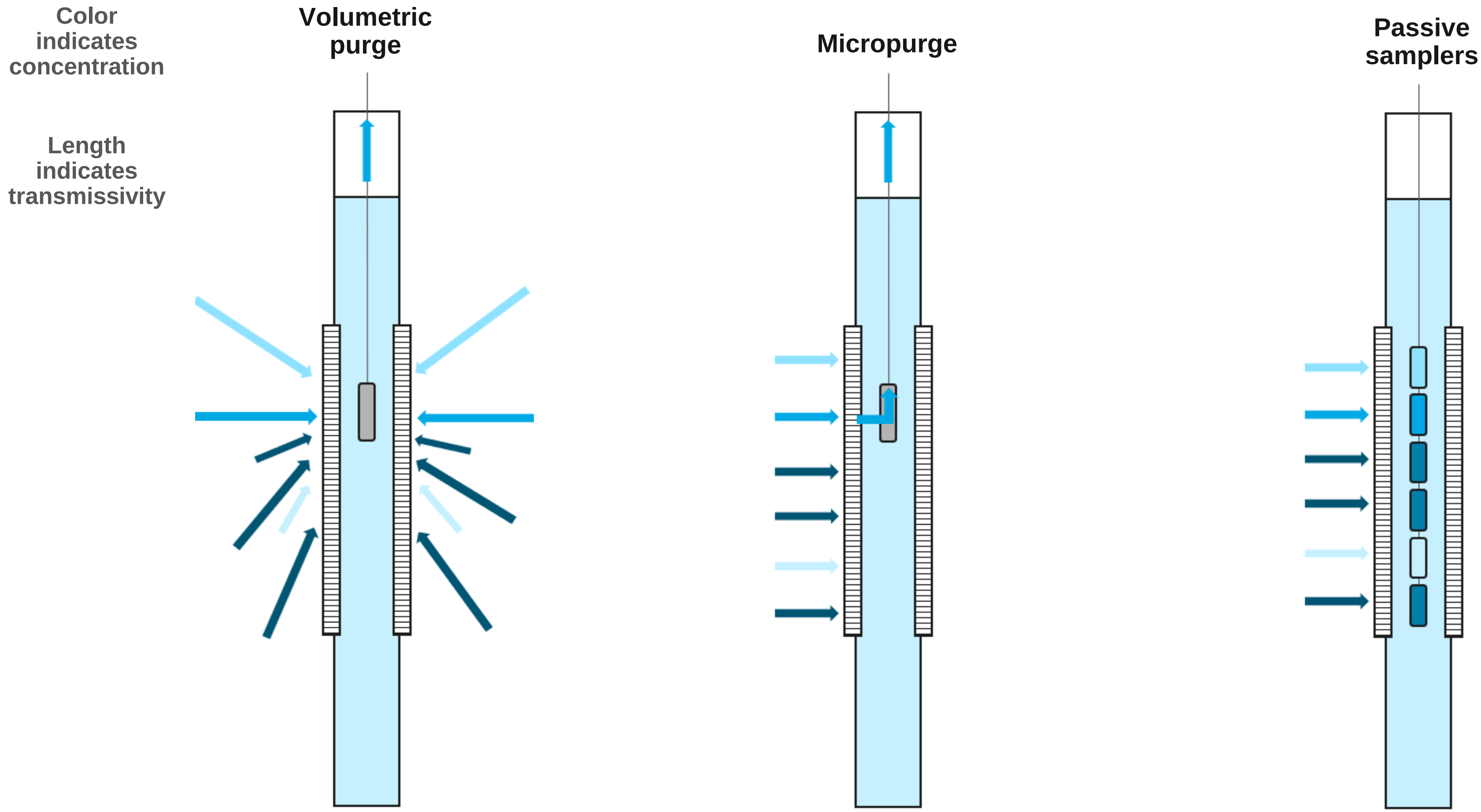


What was collected

- Field parameters
- 3 types of water samples: volumetric, micropurge, passive sampler
- Metals
- Major anions and cations
- Nitrogen compounds
- Alkalinity
- Total organic carbon
- Radionuclides
- Isotopes
- Dissolved gases (CFCs)
- Geophysical data
- Field Hach analyses: dissolved oxygen and ferrous iron

Results by sampling method

- Volumetric purge
  - 3 casing volumes
  - Parameter stability
- Micropurge: collection of first water
- Passive samplers: collection of equilibrated water



- Direct sample of aquifer water
- 3D spatial average
- More transmissive zones dominate, but pulls from low transmissivity units
- Clears well of misrepresentative water prior to sampling

- Direct sample of well water at discrete depth
- If tight formation, sample is solely well water
- <u>Should be roughly equivalent to passive sampler data at same depth</u>

- Equilibrate with water in well
- Time-weighted average of all water through well over entire deployment (4 weeks)
- Theory: represents water flowing through formation at that discrete depth

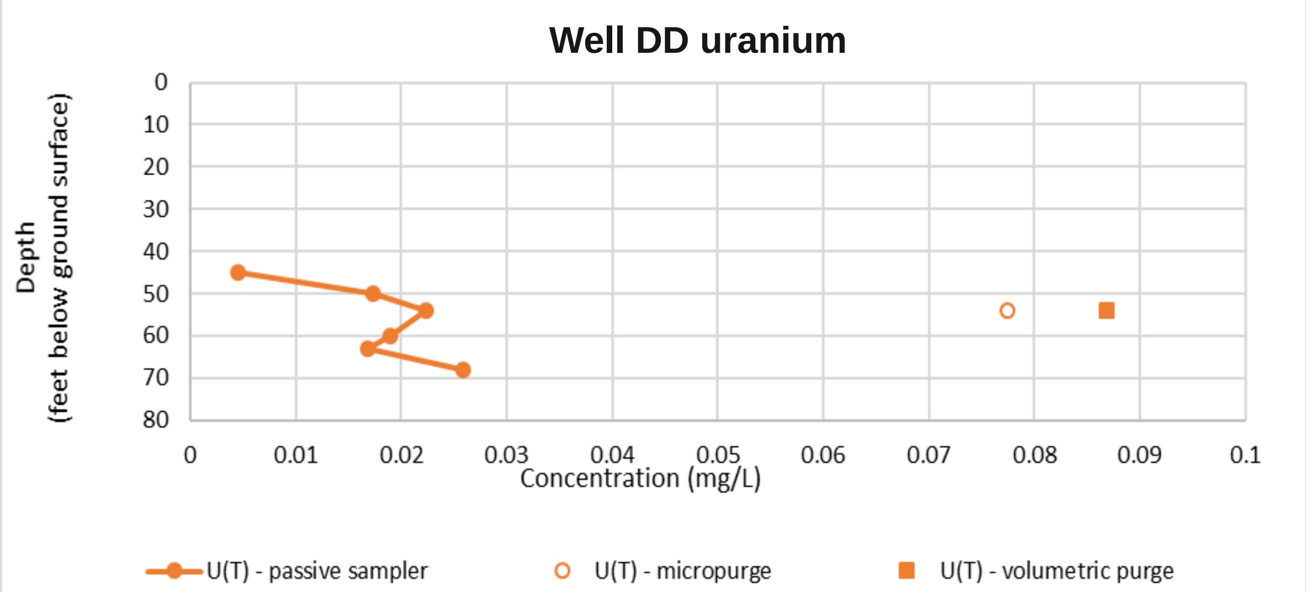
Results by sampling method

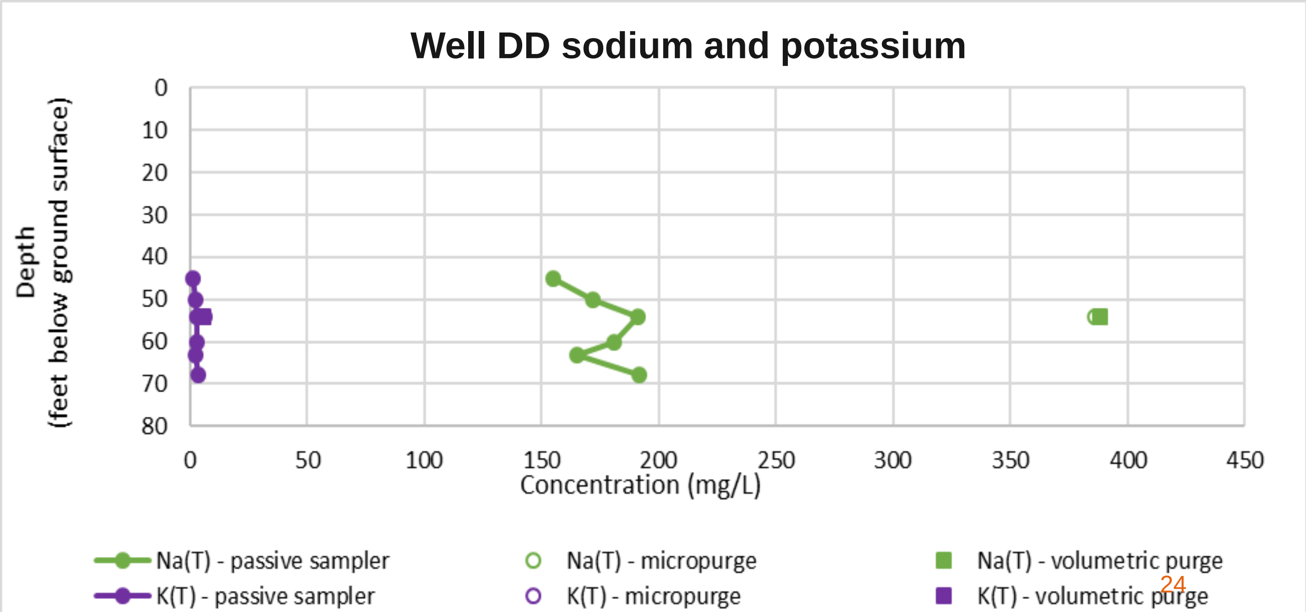
volumetric purge
micropurge
passive samplers

Passive sampler << micropurge or volumetric purge

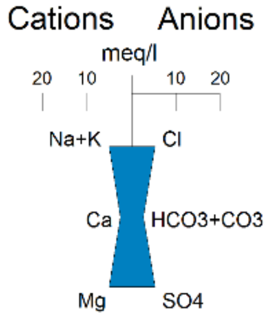
Passive sampler ≠ micropurge at same depth

Conservative ions did not equilibrate

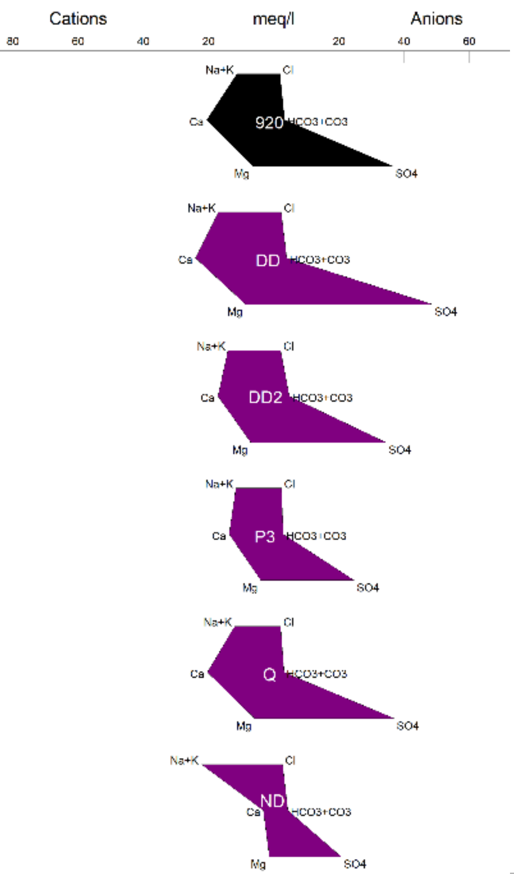




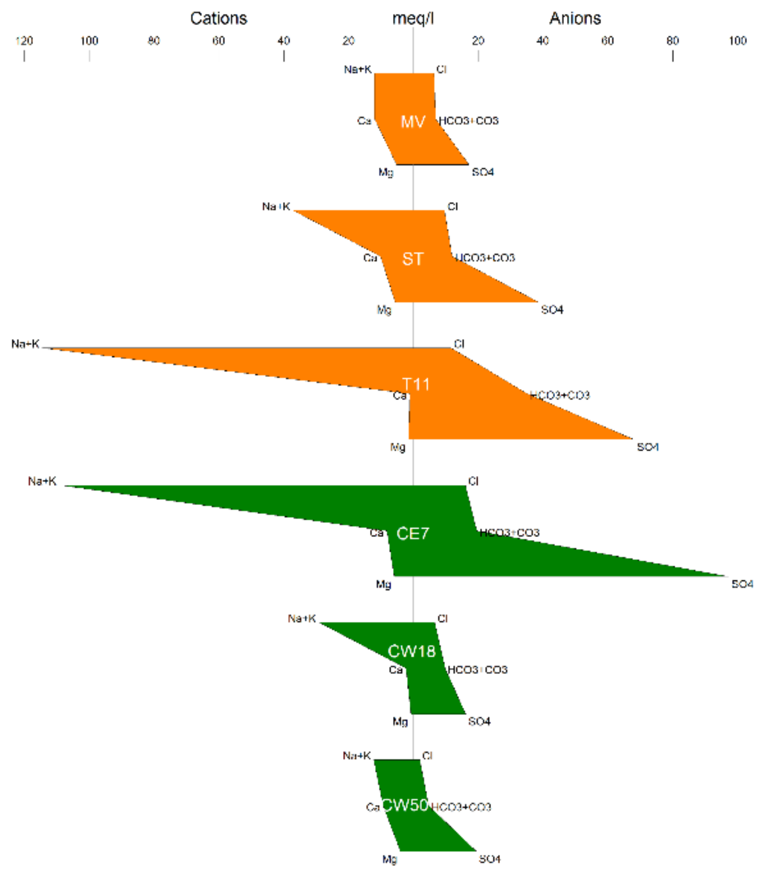
Geochemistry



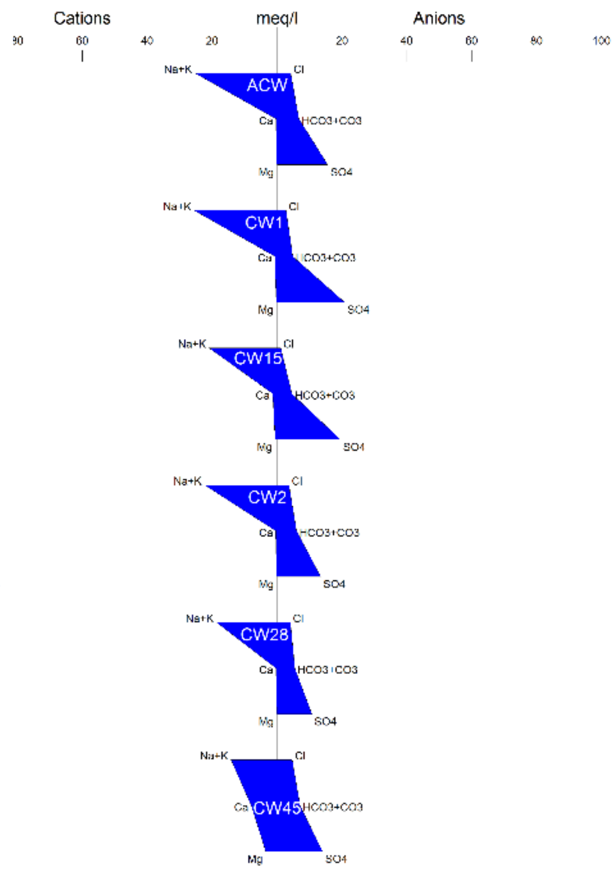
Stiff Diagrams: Upgradient wells



Alluvium (orange) and Upper Chinle (green)



Middle Chinle



Geochemistry

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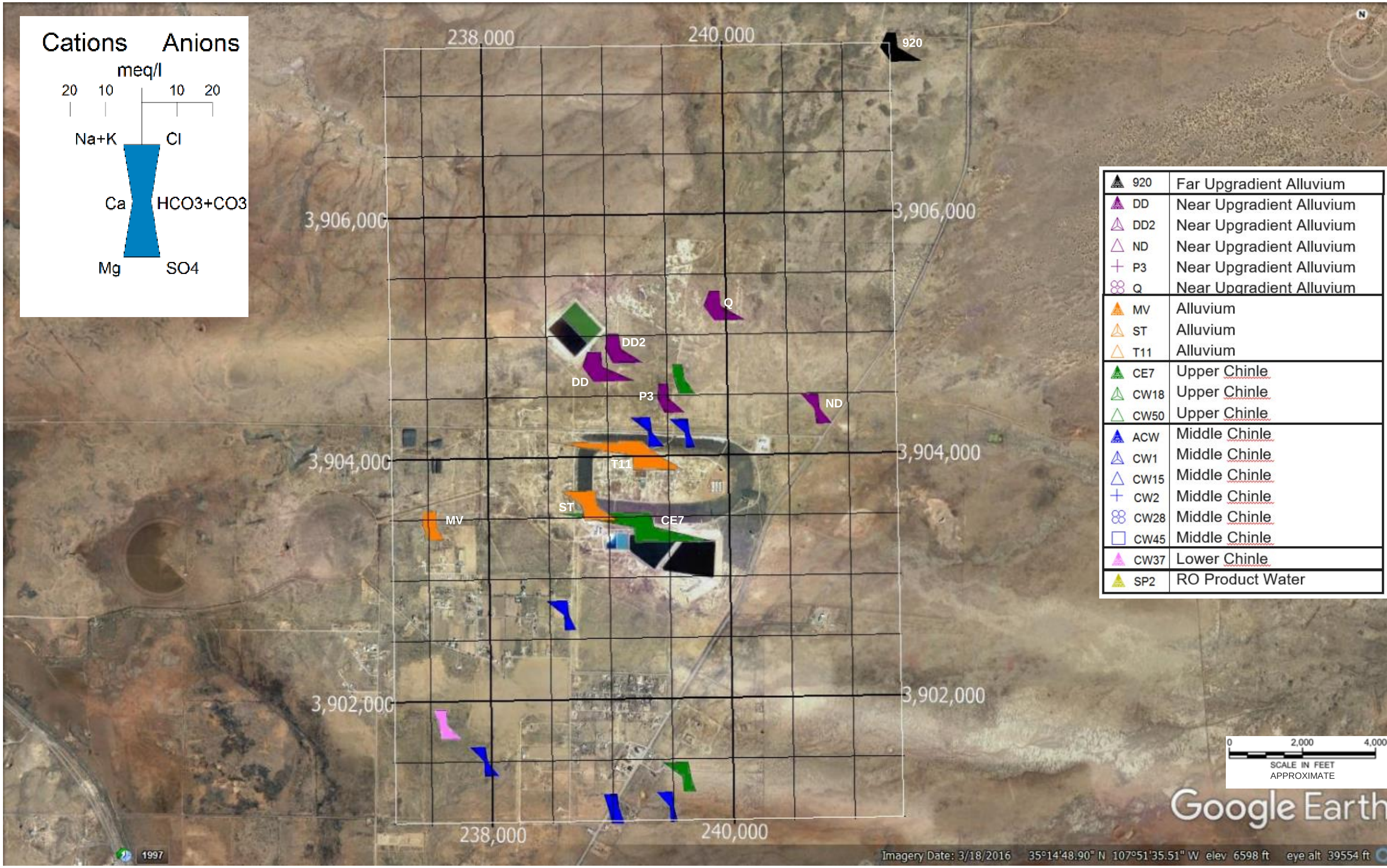
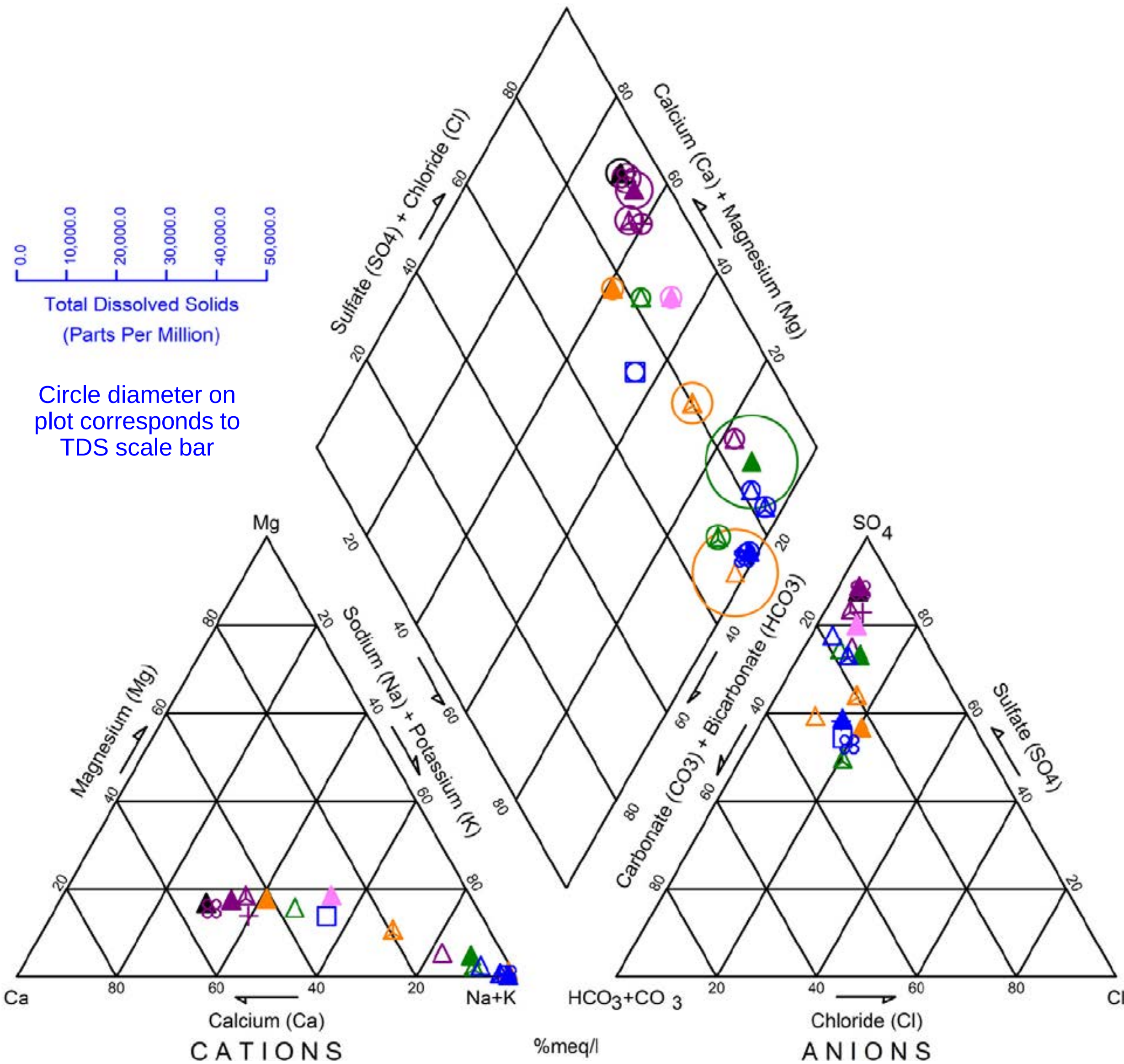
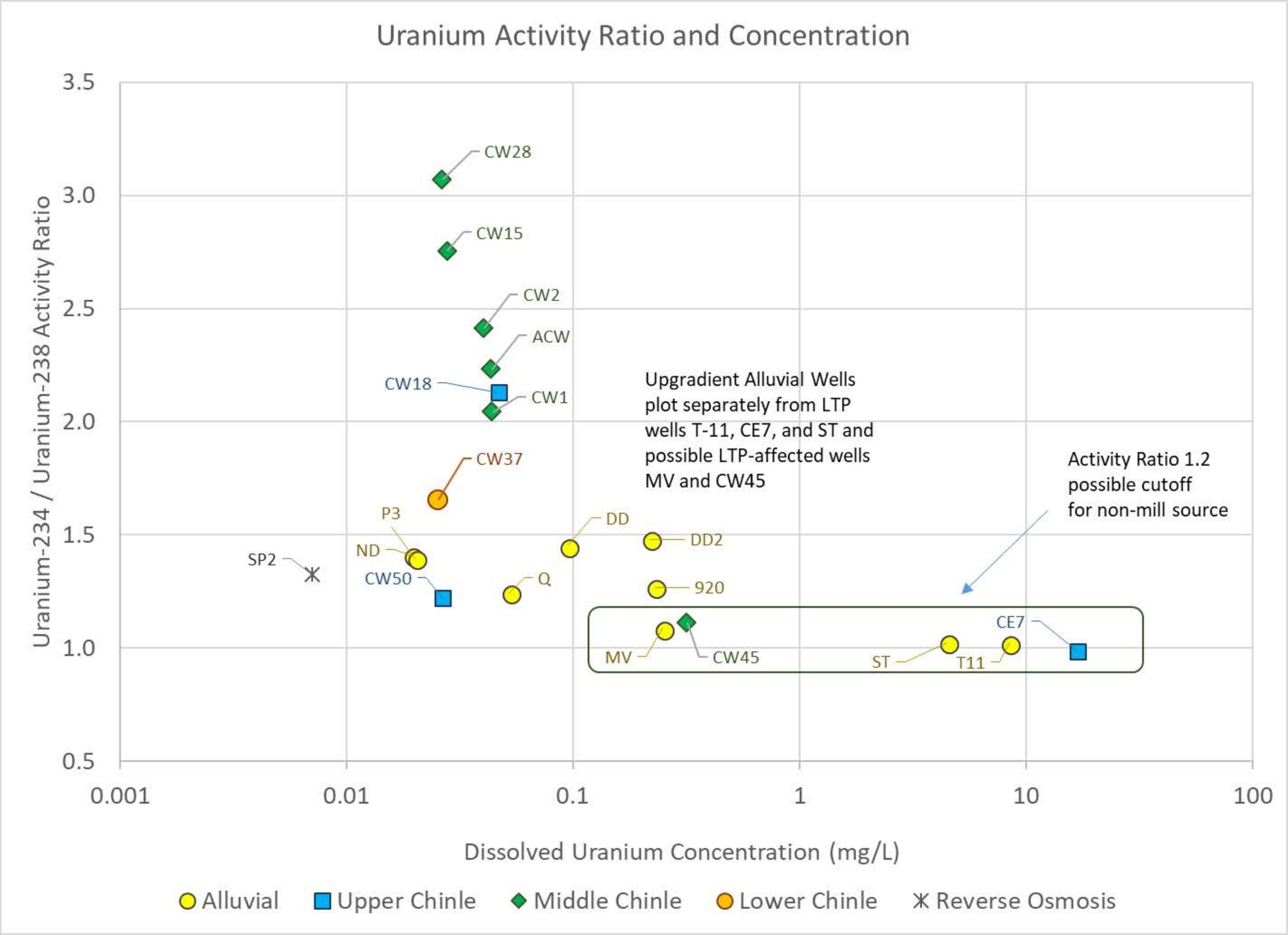


Geochemistry

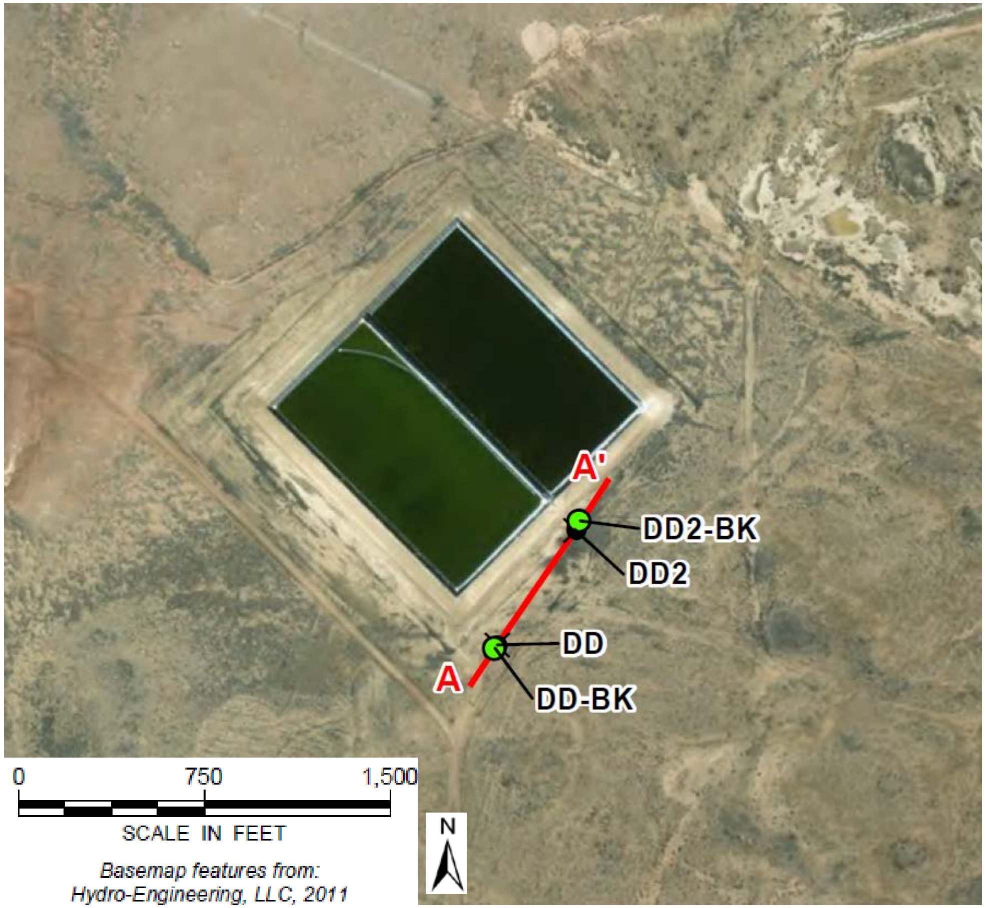


▲	920	Far Upgradient Alluvium
▲	DD	Near Upgradient Alluvium
△	DD2	Near Upgradient Alluvium
△	ND	Near Upgradient Alluvium
+	P3	Near Upgradient Alluvium
ꕥ	Q	Near Upgradient Alluvium
▲	MV	Alluvium
△	ST	Alluvium
△	T11	Alluvium
▲	CE7	Upper Chinle
△	CW18	Upper Chinle
△	CW50	Upper Chinle
▲	ACW	Middle Chinle
△	CW1	Middle Chinle
△	CW15	Middle Chinle
+	CW2	Middle Chinle
ꕥ	CW28	Middle Chinle
□	CW45	Middle Chinle
▲	CW37	Lower Chinle
▲	SP2	RO Product Water


Uranium Activity Ratio and Concentration
Uranium-234 / Uranium-238 Activity Ratio
Dissolved Uranium Concentration (mg/L)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.001
0.01
0.1
1
10
100
CW28
CW15
CW2
ACW
CW18
CW1
CW37
P3
ND
SP2
CW50
Q
DD
DD2
920
MV
CW45
ST
T11
CE7
Upgradient Alluvial Wells plot separately from LTP wells T-11, CE7, and ST and possible LTP-affected wells MV and CW45
Activity Ratio 1.2 possible cutoff for non-mill source
Alluvial
Upper Chinle
Middle Chinle
Lower Chinle
Reverse Osmosis

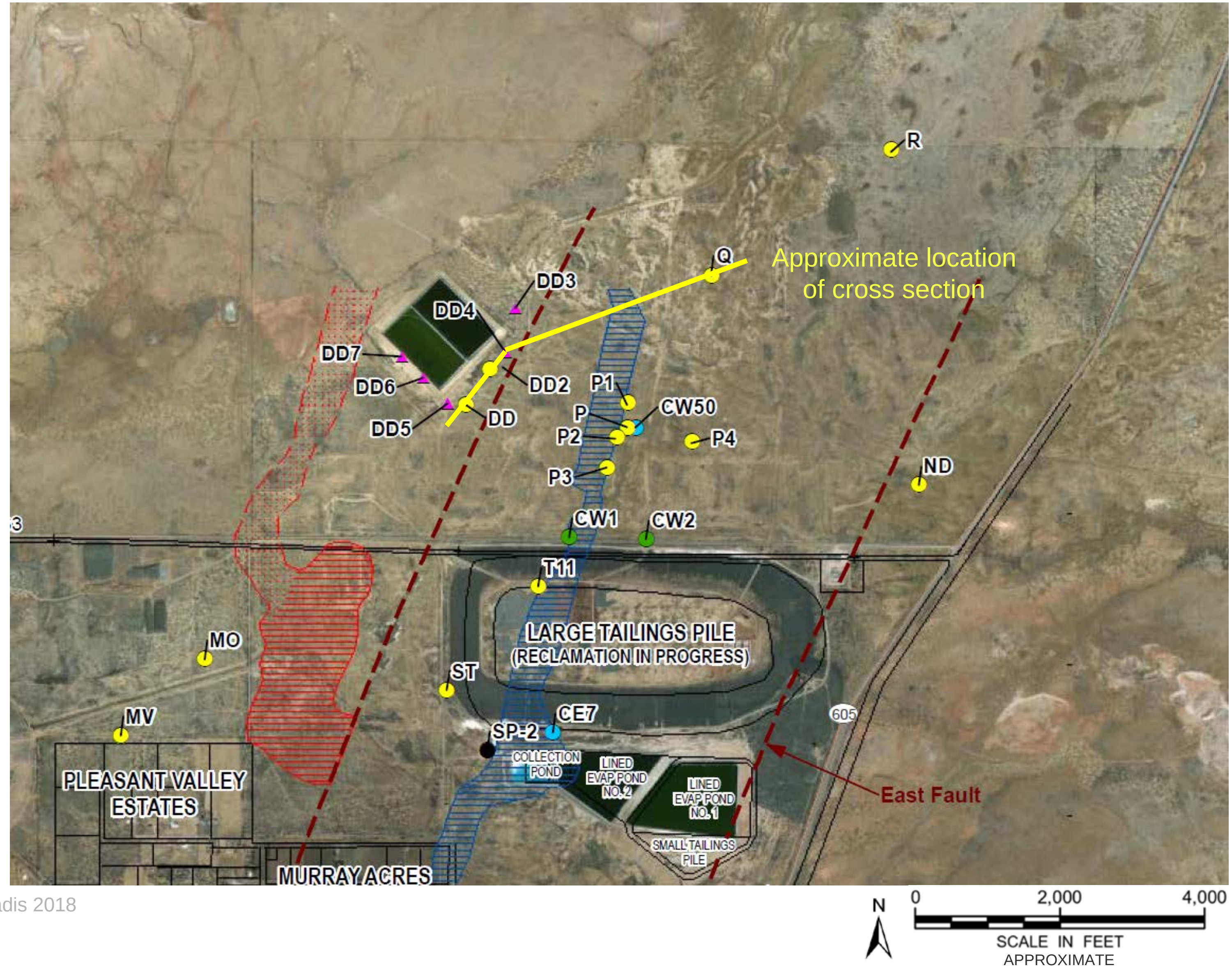
Detailed analysis of lithology, geochemistry, and mineralogy at DD-BK and DD2-BK

Location of new boreholes

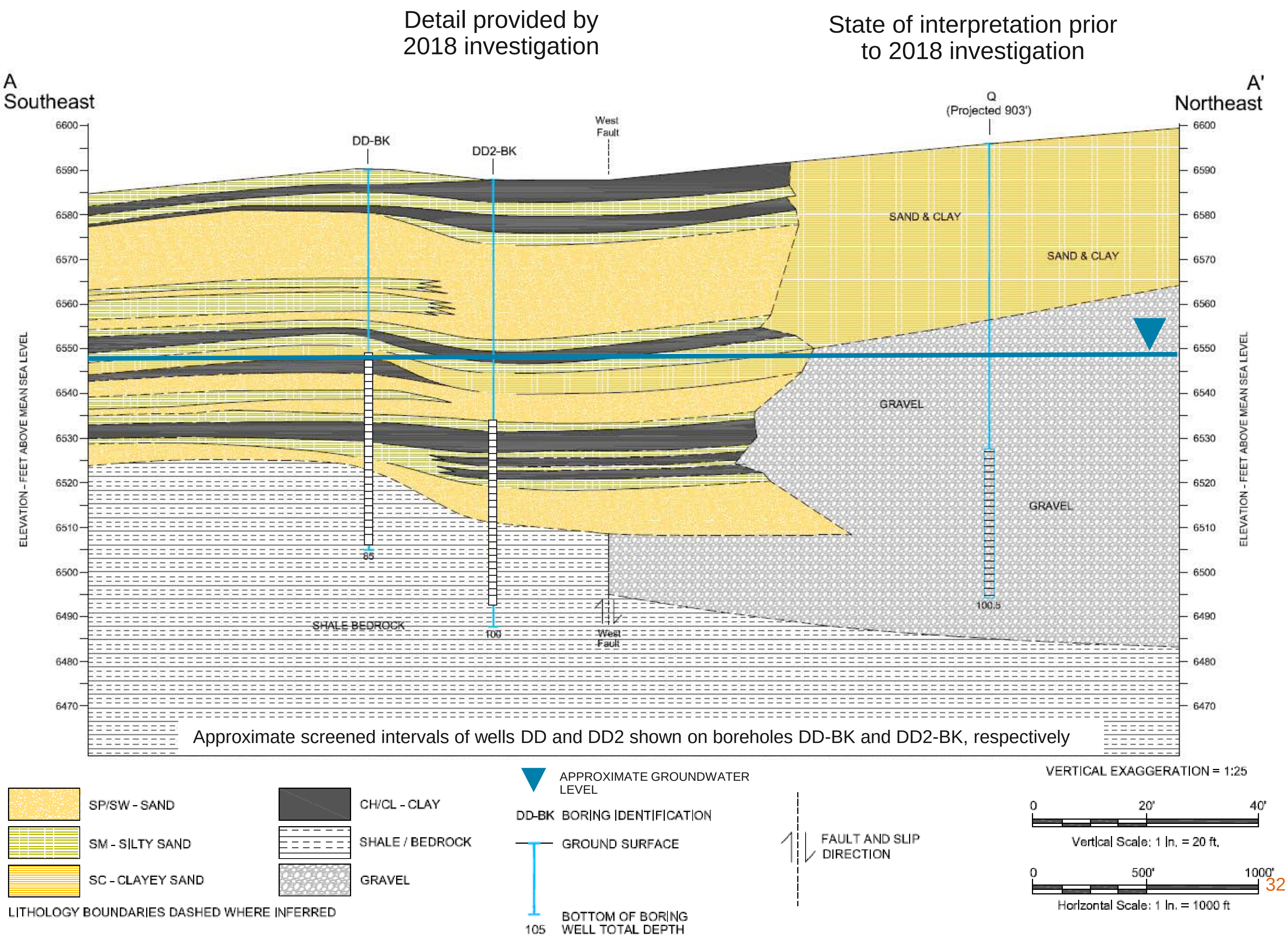


- Previous logging by driller, not geologist, with a mud rotary rig
  - Poor sample quality, very little sample visibility, low-resolution core-logging
- This event = high resolution logging, sonic rig
- Revised cross section for this area
- Alternating sands/silts/clays over shale
- Consistent with fluvial deposition of eroded grains from nearby source
- Sub-angular to sub-rounded grains: sediments transported, but not extreme distances

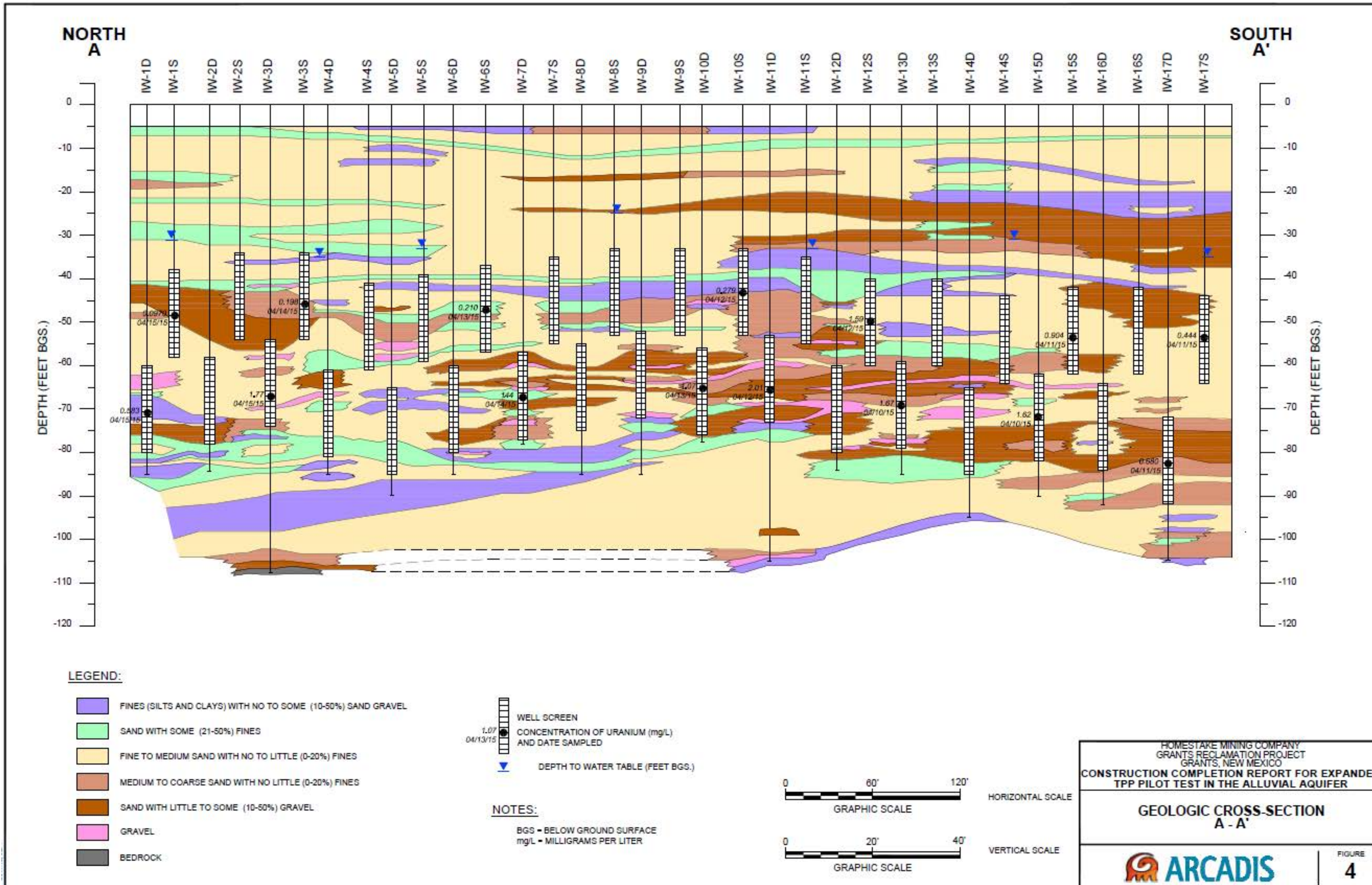
Revised understanding of alluvial geology



Revised Cross-section



Additional example of heterogeneity of the alluvial aquifer matrix (west side of LTP)



Sampling and analysis

Samples collected covering both saturated and unsaturated zones

Sample location selection based on lithological characteristics and on dynamic spectral gamma data

Static spectral gamma collected at each sampling location

Analyses

- Total metals
- Alkaline leaching test (modified SPLP based on Kohler et al. 2004)
- Particle size analysis
- Microscopic and spectroscopic analysis

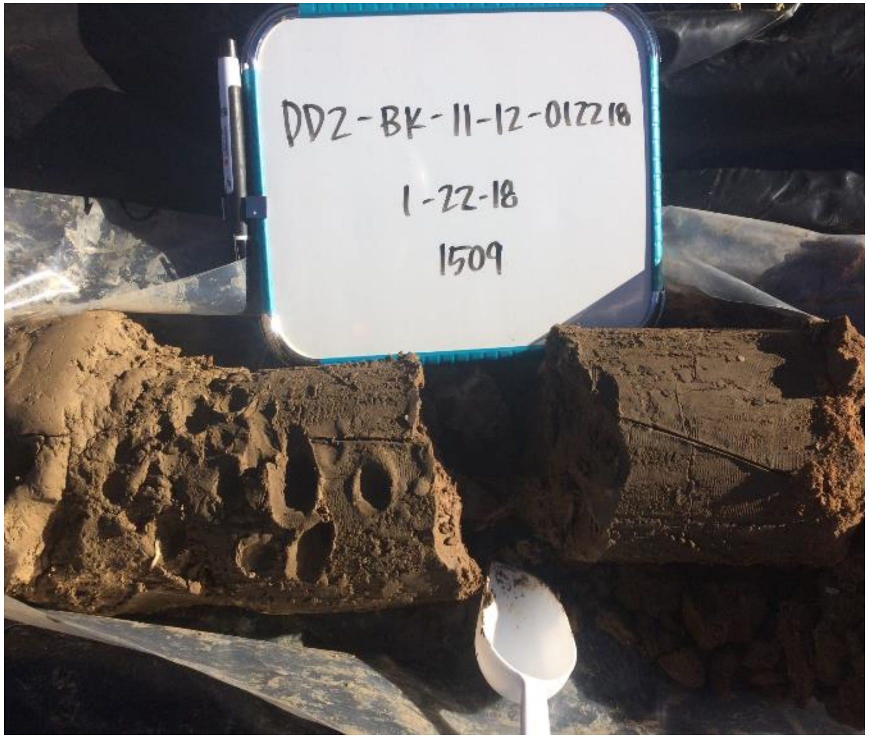
Samples with detected uranium

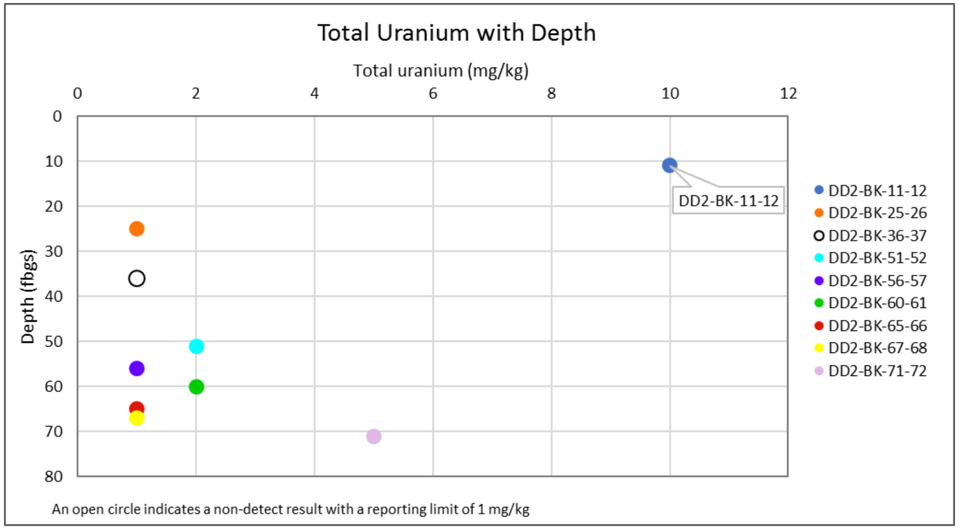
Sample ID	Alluvium zone	Total uranium concentration (mg/kg)	Alkaline SPLP leached uranium (mg/L)	Field-logged lithology	ACZ Particle Size Analysis Lithology	DCM analysis
DD2-BK-11-12-012218	unsaturated	10	0.179	CLAY	Clay	Yes
DD2-BK-71-72-012318	saturated	5	0.0305	Gravely SAND with silt	Sand	Yes
DD2-BK-51-52-012318	saturated	2	0.0086	Silty SAND	—	Yes
DD2-BK-60-61-012618	saturated	2	0.0086	CLAY with trace sand	—	Yes
DD2-BK-25-26-012218	unsaturated	1	0.0477	SAND with trace silt	Sand	Yes
DD2-BK-56-57-012318	saturated	1	0.0079	Silty SAND	—	No
DD2-BK-65-66-012318	saturated	1	0.0080	Sandy SILT	—	No
DD2-BK-67-68-012618	saturated	1	0.0180	CLAY	—	No
DD-BK-36-37-012518	unsaturated	1	0.0127	CLAY	Clay	Yes
DD-BK-58-59-012618	saturated	1	0.0032	CLAY	—	Yes
DD-BK-9-10-012518	unsaturated	1	0.0022	CLAY with trace sand	Clay	Yes

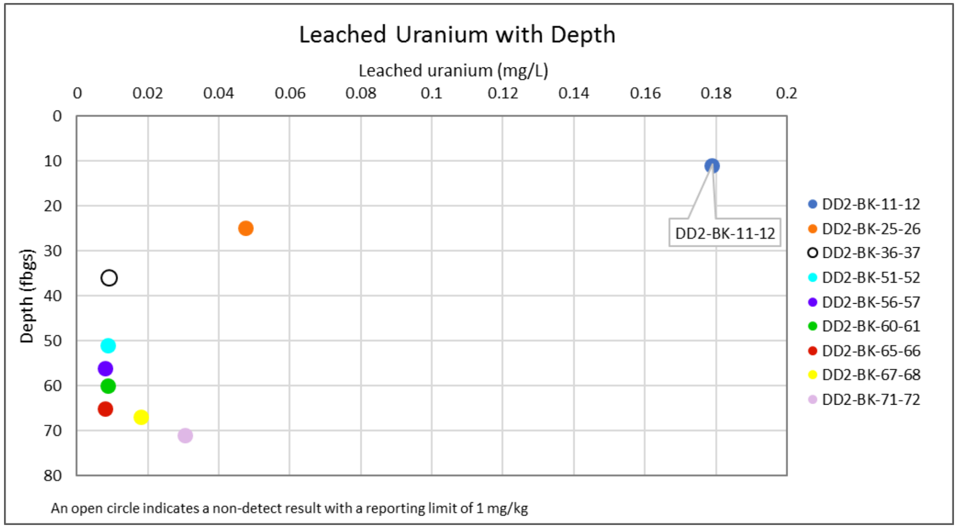
19 samples (excluding duplicate) were analyzed by ELI, only those with detectable total uranium concentrations are shown in the table

DD2-BK-11-12-012218

- Total uranium concentration: 10 mg/kg
- Alkaline SPLP leached uranium: 0.179 mg/L
- Lithology: Clay

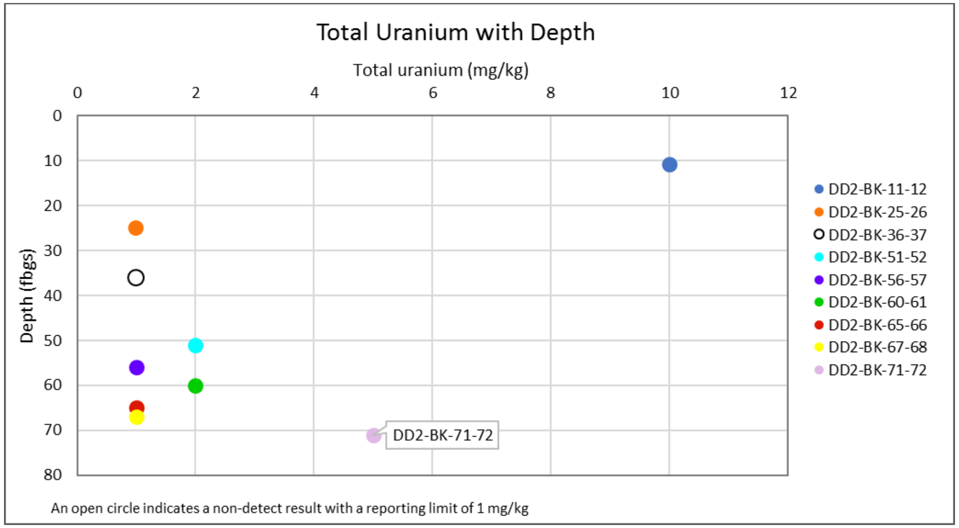


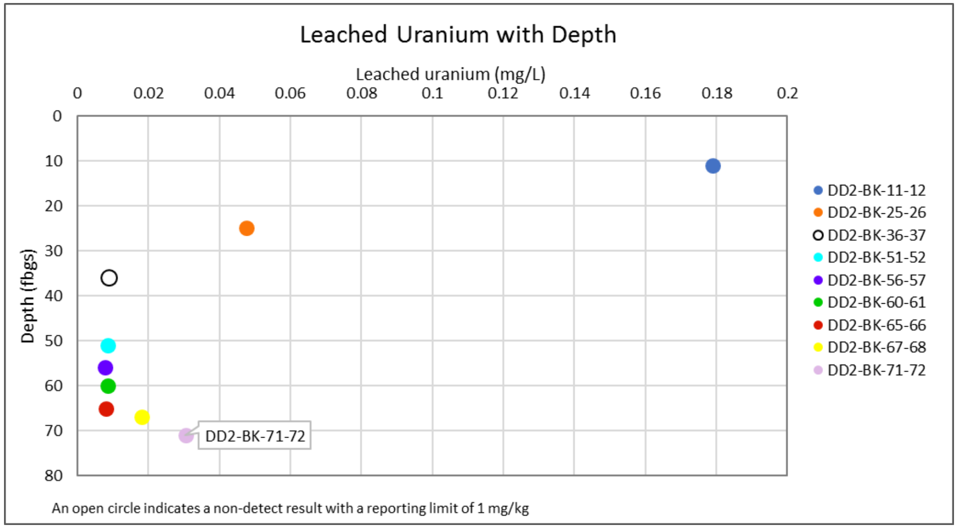




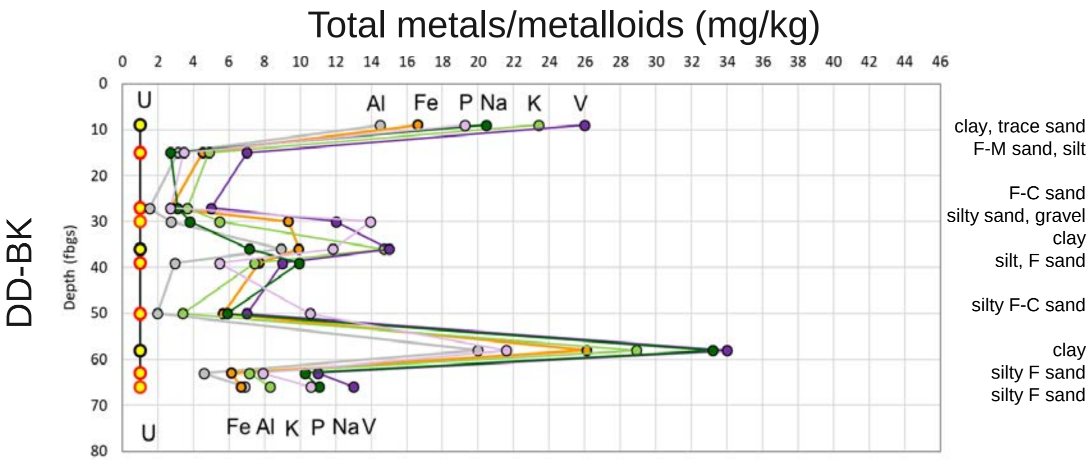
DD2-BK-71-72-012318

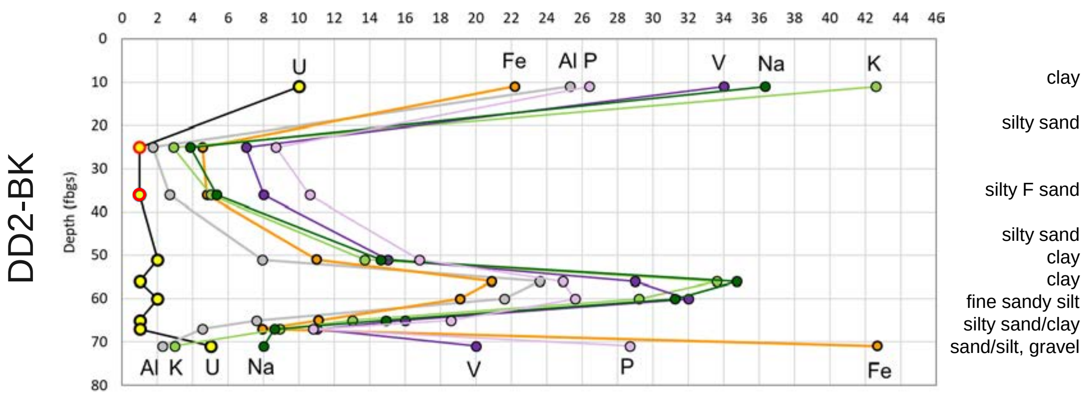
- Total uranium concentration: 5 mg/kg
- Alkaline SPLP leached uranium: 0.0305 mg/L
- Lithology: Gravely sand with silt





Soil chemistry – total metals





Red circle = non-detect; reporting limit shown
Total Al and Fe/1000; K/100; Na, P/20

Soil chemistry – total metals and leaching

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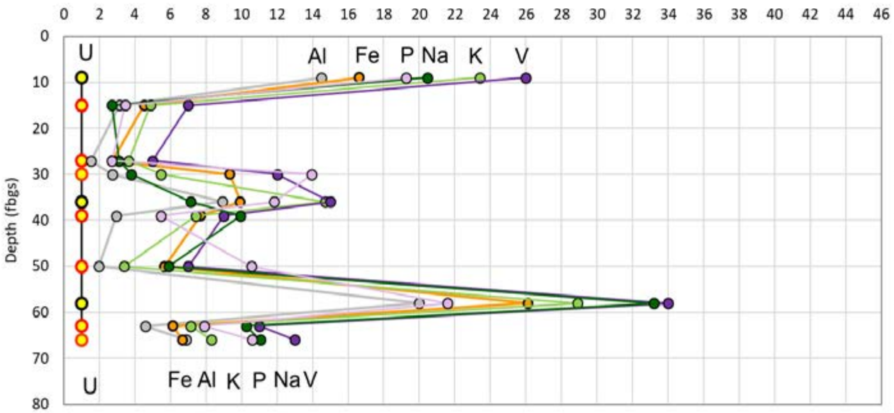
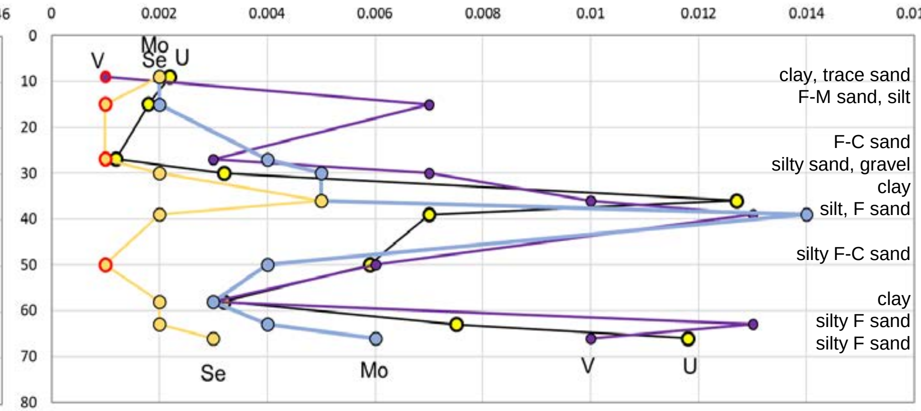
Leached in an alkaline (simulated groundwater) extraction

Total metals/metalloids (mg/kg)

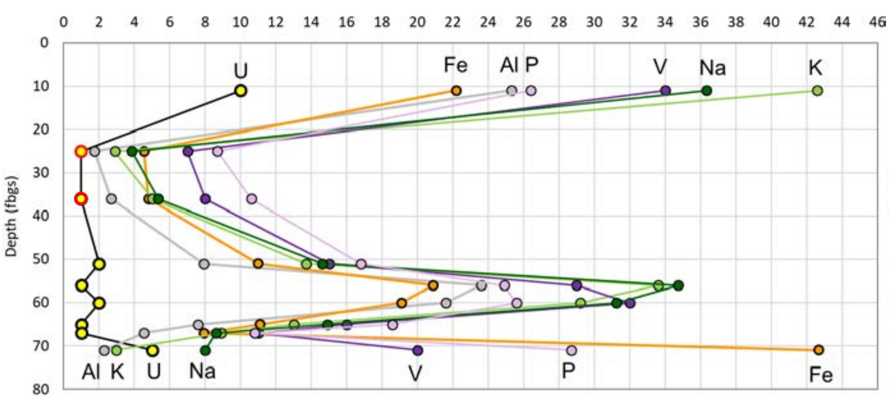
Leached metals/metalloids (mg/L)

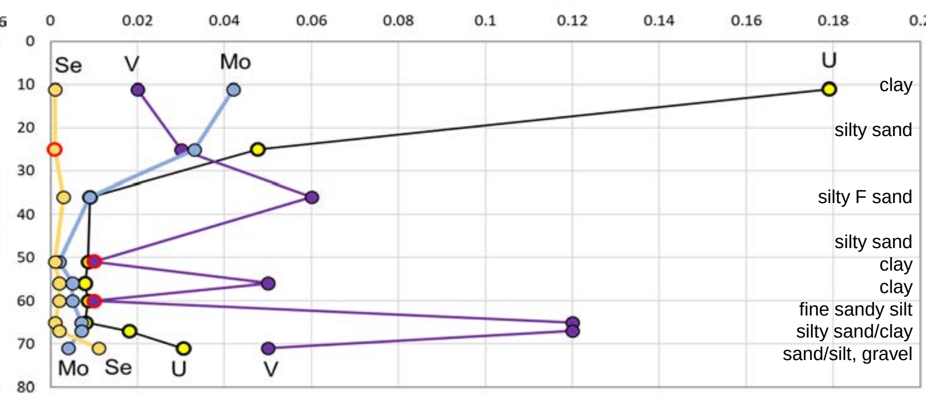
DD-BK





DD2-BK





Red circle = non-detect; reporting limit shown
Total Al and Fe/1000; K/100; Na, P/20

Iron oxide pseudomorphs of pyrite framboids

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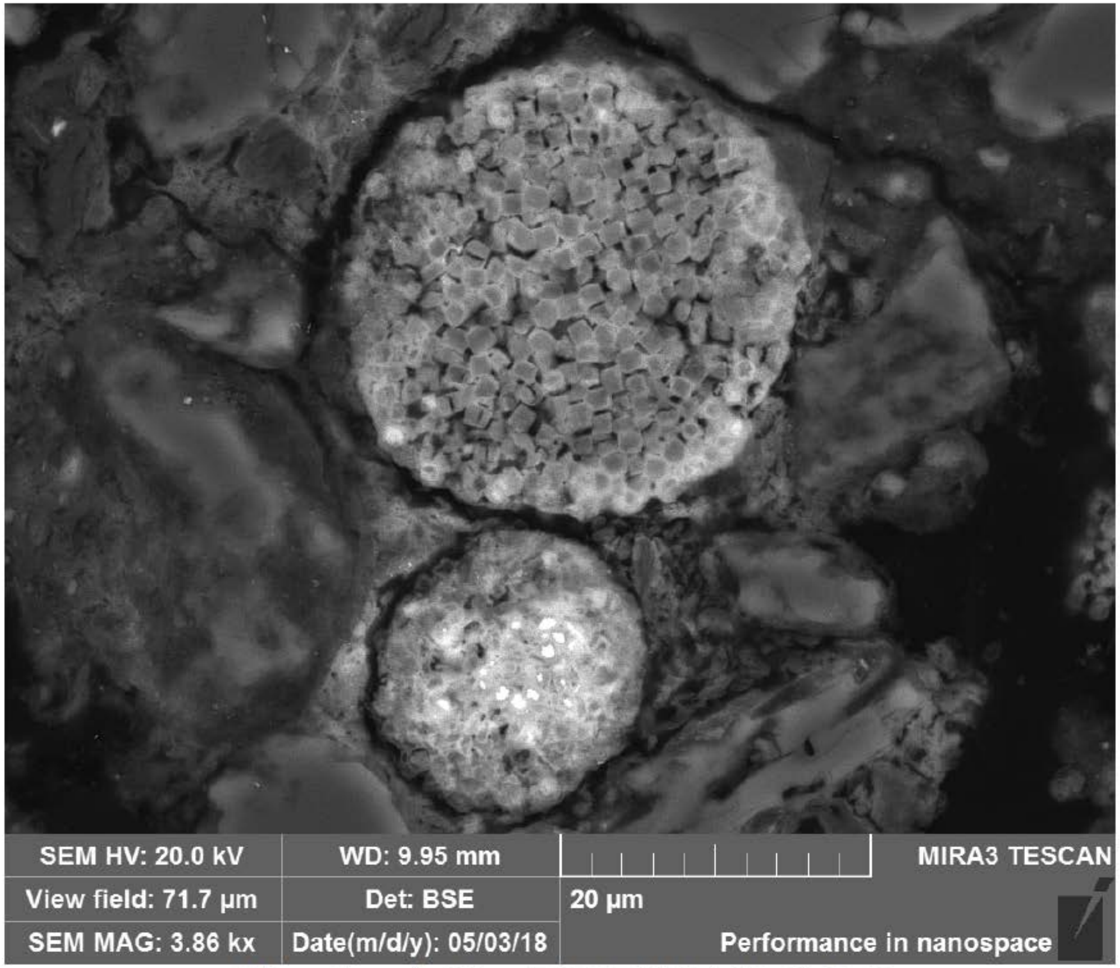


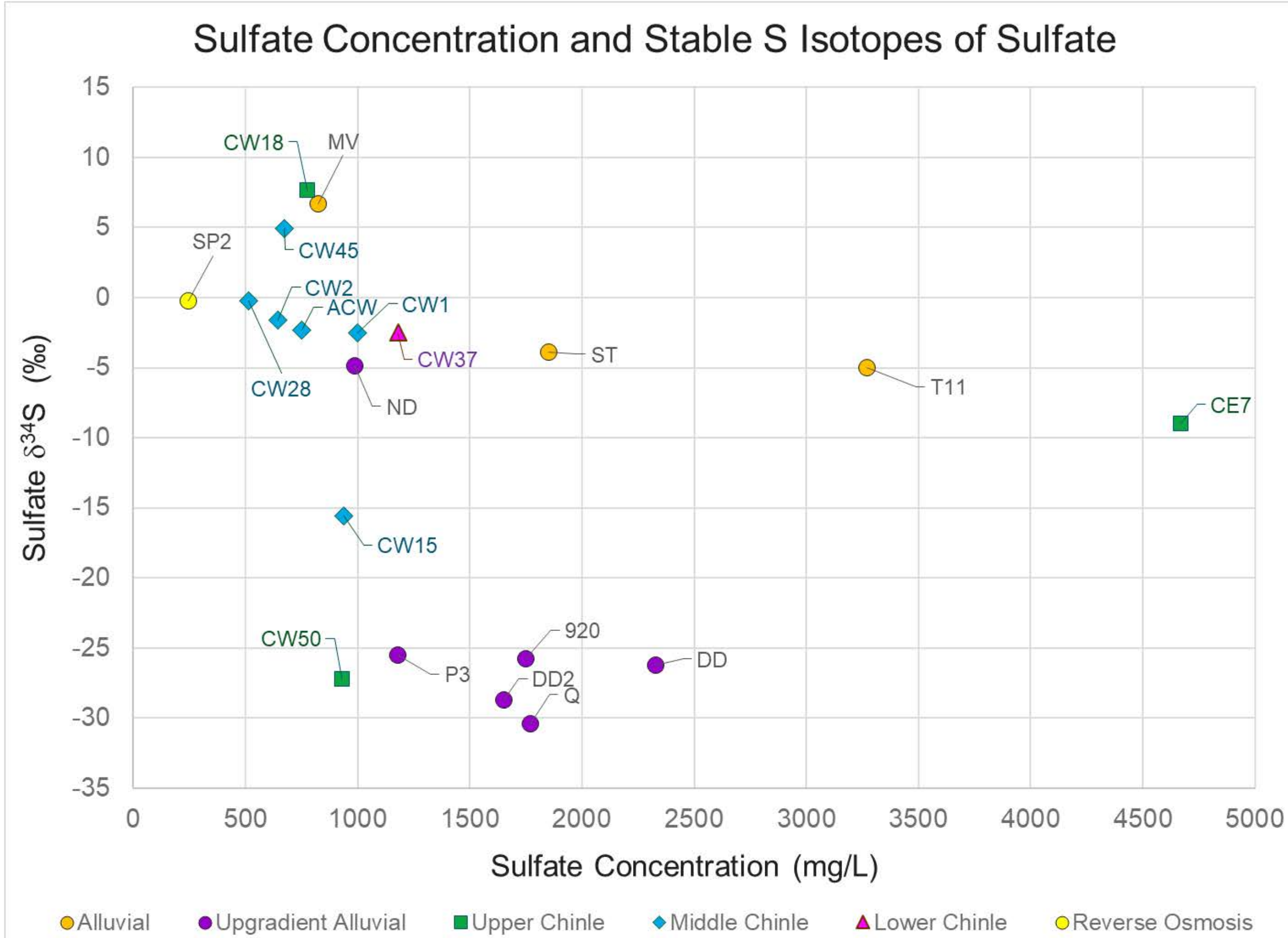
Client Sample No.: **DD2-BK-51-52-012318**

Backscatter image of iron oxide pseudomorphs after pyrite framboids sit in a matrix of clay with quartz/feldspar grains. The smaller pseudomorph contains bright relict pyrite – 3,860X.

Notes
µm – microns
BSE – backscatter electron detector
HV – high voltage
kx – thousand times magnification
kV – kilovolts
m/d/y – month/day/year
mm – millimeters
WD – working distance
X – times magnified

Sulfate S and O Isotopes

- Stable sulfur isotopes suggest pyrite oxidation is primary sulfate source due to depleted nature.
- Samples with lower sulfate concentrations and more positive $\delta^{34}S$ values suggest sulfate derived from combination of pyrite oxidation and gypsum dissolution.
- Use of sulfuric acid in U ore processing (Skiff and Turner 1981) may account for the higher sulfate concentration and heavier isotope signature from mills/tailings (e.g., wells T11, ST, CE7 near the large tailing pile) since sulfuric acid has $\delta^{34}S$ ~ -8 to 32‰



Sulfate S and O Isotopes

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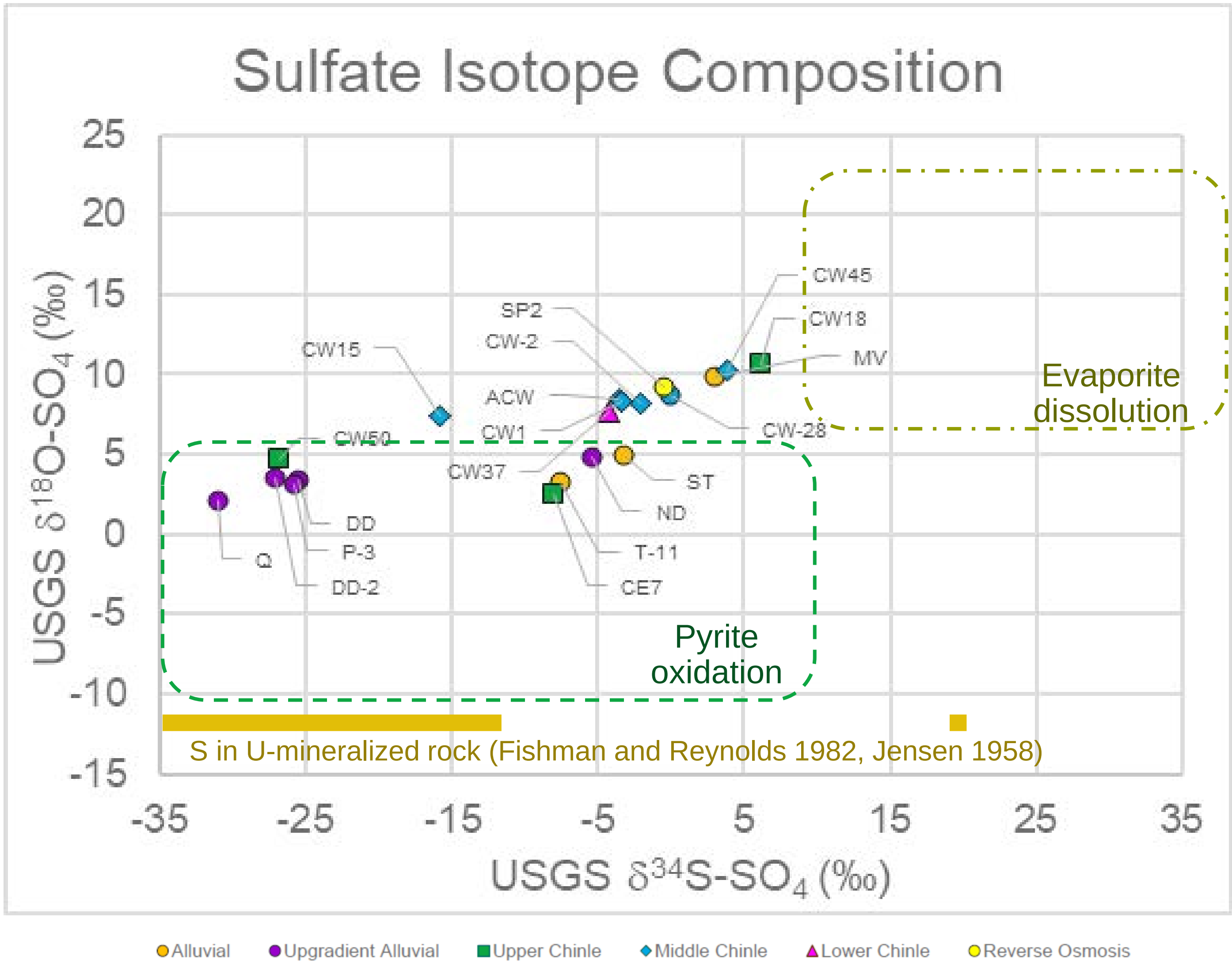
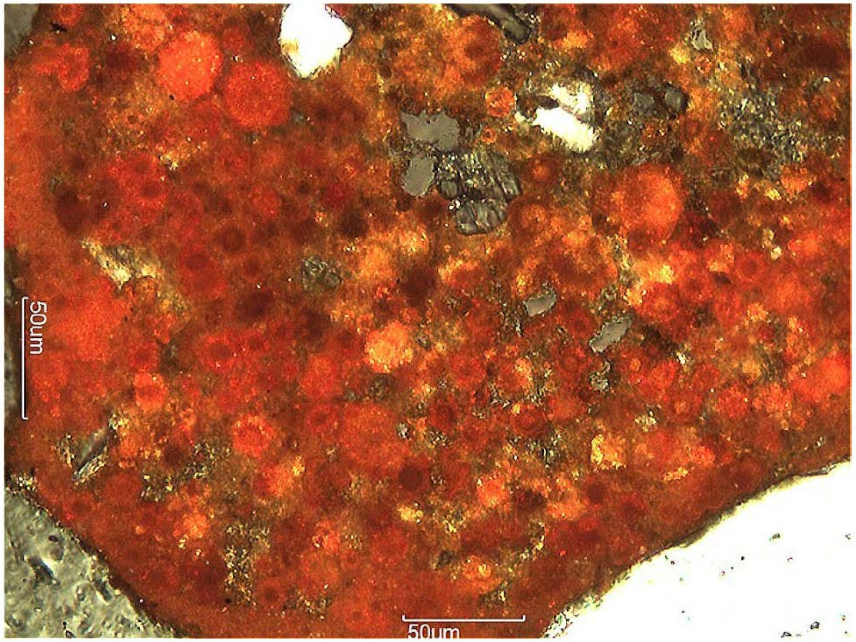
- Region contains naturally-occurring sulfide minerals (pyrite) in U-mineralized rocks and U-mineralized sediment present in alluvial aquifer
- Oxidation of sulfur from sulfide minerals results in dissolved sulfate formation
- The greatest negative signatures come from areas that experience cycles of sulfide formation/oxidation

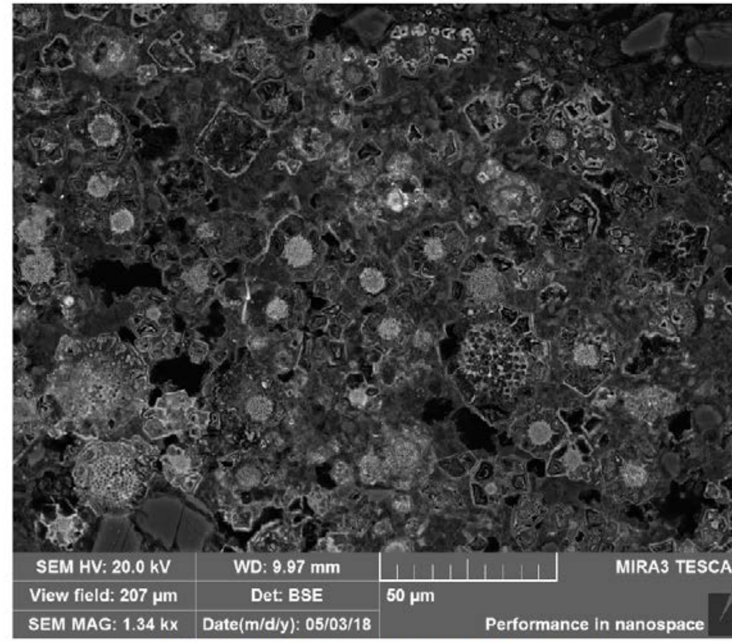


Iron oxide pseudomorphs of pyrite framboids



Client Sample No.: **DD2-BK-25-26-012218**

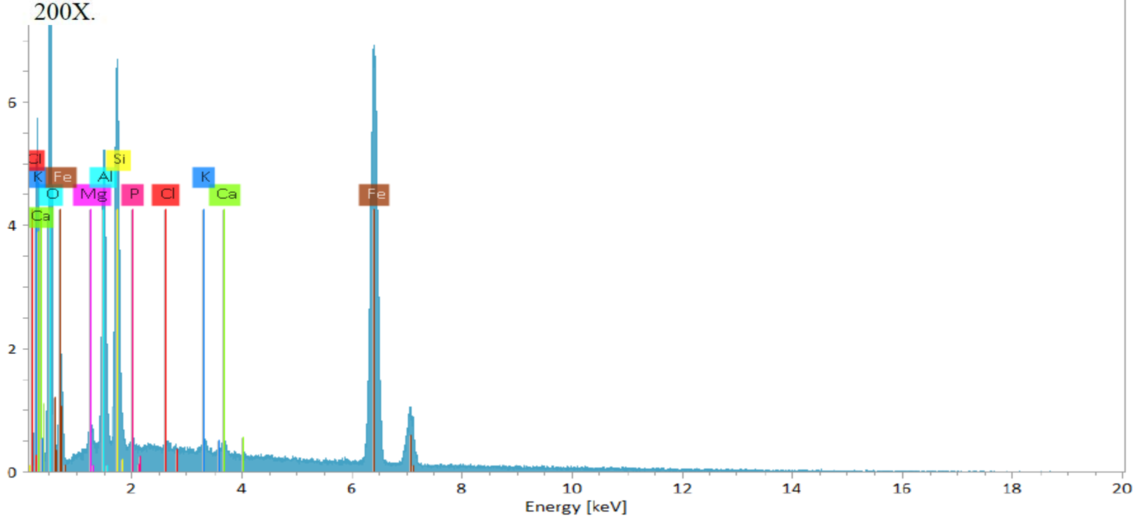
Iron oxide pseudomorphs after pyrite and pyrite framboids. Reflected light crossed Nichols – 200X.



Client Sample No.: **DD2-BK-25-26-012218**

Backscatter image of iron oxide pseudomorphs after pyrite cubes and framboids – 1,340X.

- Unsaturated zone
- Massive/ lithic



Notes

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cps/eV – count per second per electron volt
HV – high voltage
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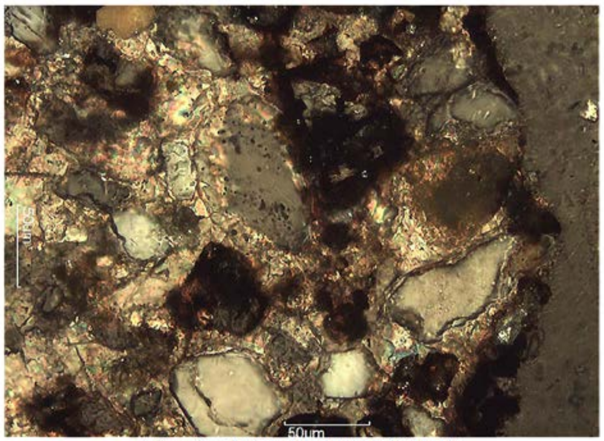
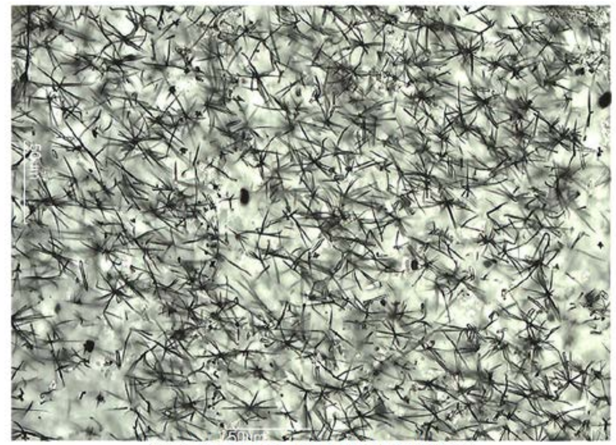
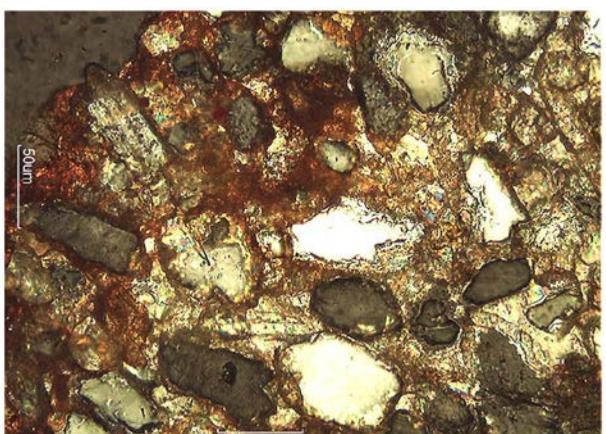
Mineralogical consortia showing quartz, feldspar, and other igneous mineralogy



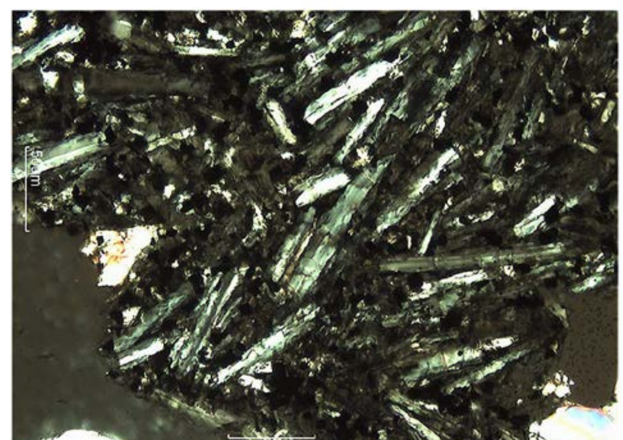
Client Sample No.: **DD2-BK-25-26-012218**
Calcite and iron oxide cement quartz/feldspar grains. Reflected light crossed Nichols – 200X.



Client Sample No. **DD2-BK-25-26-012218**
otropic volcanic glass riddled with unknown opaque, acicular crystallites. Polarized light – 250X.



Client Sample No.: **DD2-BK-71-72-012318**
Calcite and iron oxide cement quartz/feldspar grains. Reflected light crossed Nichols – 200X.



Client Sample No.: **DD2-BK-71-72-012318**
Fragment of basalt showing lath shaped plagioclase. Polarized light – 200X.

Notes

X – times magnified

Mineralogical conclusions

- Presence of both geochemically reduced and oxidized minerals shows:
  - Heterogeneity in the mineralogical environment,
  - Existence of microenvironments, and
  - Transitions from reducing to oxidizing conditions, affecting uranium mobility.
    - Pyrite pseudomorphs oxidized to iron oxides
    - Pyrite/pyrite pseudomorphs appear in both saturated and unsaturated zones
    - The transition from reduced to oxidized environ could liberate uranium by direct oxidation or through dissolution of uranium associated with pyrite
- Clays here have abundant organic carbon and may serve as a reservoir for reduced uranium, with slow diffusion of water and oxygen resulting in leaching of uranium
  - Clays here contain sulfide minerals including pyrite (iron), chalcopyrite (copper), galena (lead), sphalerite (zinc). This assemblage shows the relative stability of pyrite

Mineralogical conclusions

- Minerals in the Morrison Fm are evident in alluvial soils near DD/DD2 (notably, feldspar)
- Mineral grain shapes in the alluvium indicate water-borne transport and deposition moderate to large distances from their origin (sub-angular to rounded grains)
- The highest uranium was in the unsaturated zone. This indicates that uranium in alluvial deposits is present due to transport/deposition of naturally uranium-rich materials over hundreds to thousands of years, not due to deposition from uranium-bearing groundwater.

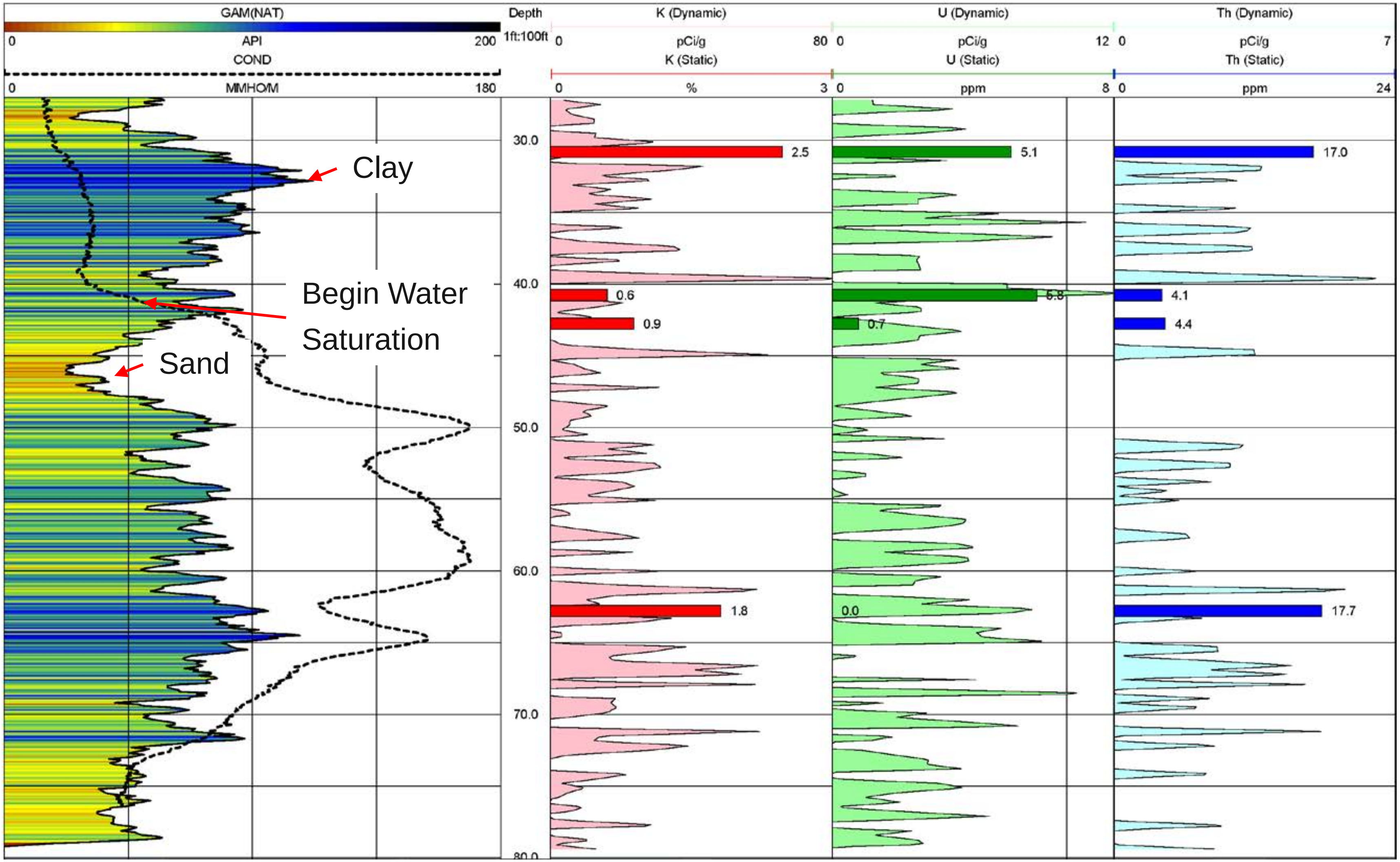
The following units are exposed immediately north of the Grants Reclamation Project (Cather 2011, USGS 1956, USGS 1970, Maxwell 1982):

- Triassic Wingate Sandstone: white eolian sandstone/siltstone (no feldspar recorded)
- Jurassic Entrada Sandstone: eolian sandstone/siltstone (no feldspar recorded)
- Todilto Limestone: thin- to thick-bedded limestone
- Summerville Formation: clean, white sand/siltstone (no feldspar recorded)
- Bluff Sandstone: clean quartz eolian sandstone
- Morrison Formation Recapture (with Poison Canyon Sandstone): fluvial mudstone/sandstone
- Morrison Formation Westwater Canyon: **fluvial <u>arkosic</u> sandstone (significant feldspar)** with interbedded mudstone
- Morrison Formation Brushy Basin Member: fluvial mudstone with some interbedded sandstone
- Dakota Sandstone: quartz sandstone that lacks feldspar (though in some places, the Dakota can have “sparse feldspar” (Maxwell 1982))

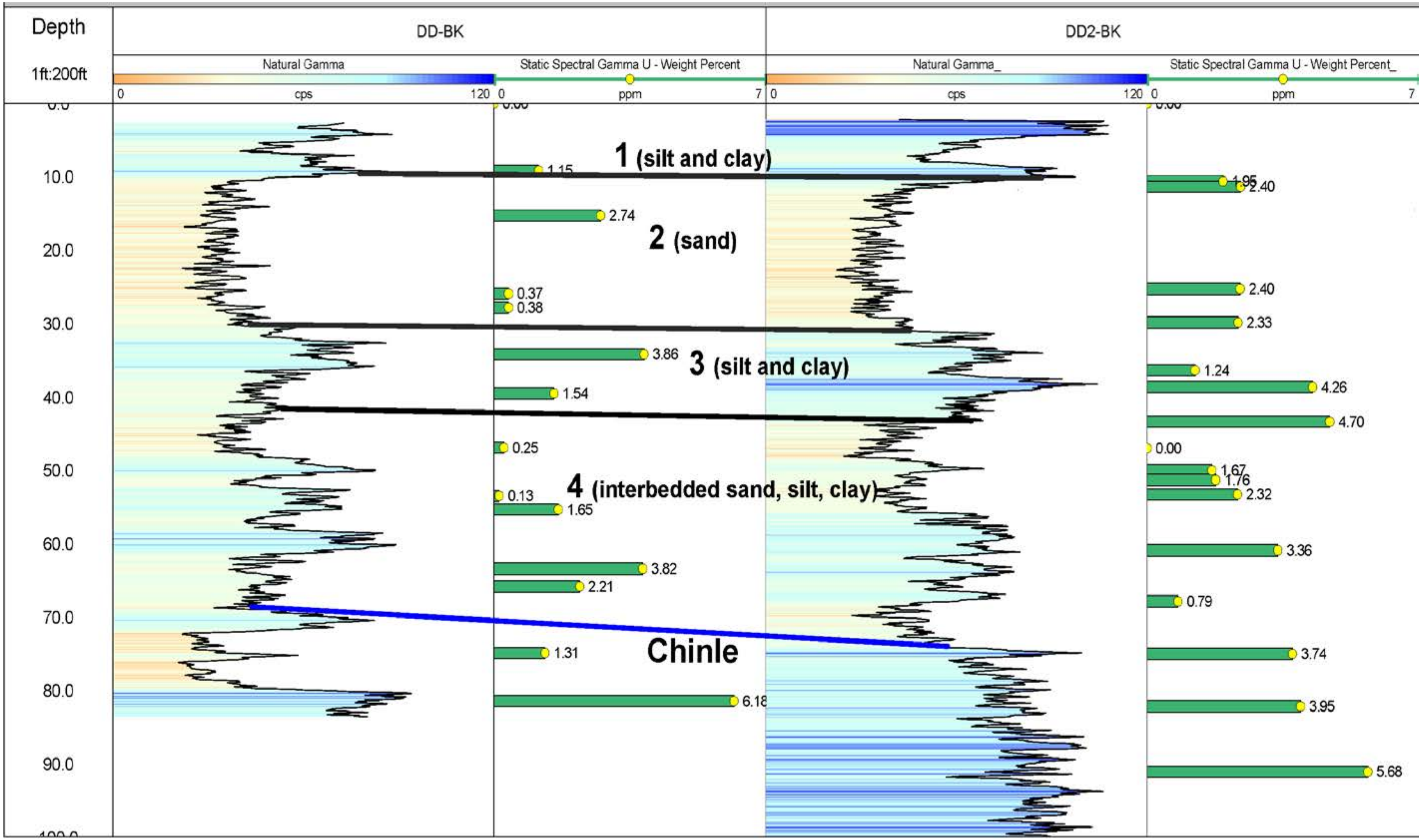
Down-hole Geophysics at DD-BK and DD2-BK

- Purpose: To provide continuous, lithological, hydrogeologic and geochemical information to supplement sampling and analysis
- Natural Gamma: Used to identify lithologies on the basis of potassium content (clays, feldspars, micas, etc.)
- Electrical Conductivity: Used to estimate water saturation, porosity, and lithology
- Spectral Gamma: Quantification of potassium, uranium and thorium (KUT) content of alluvium

Example Log – Well DD



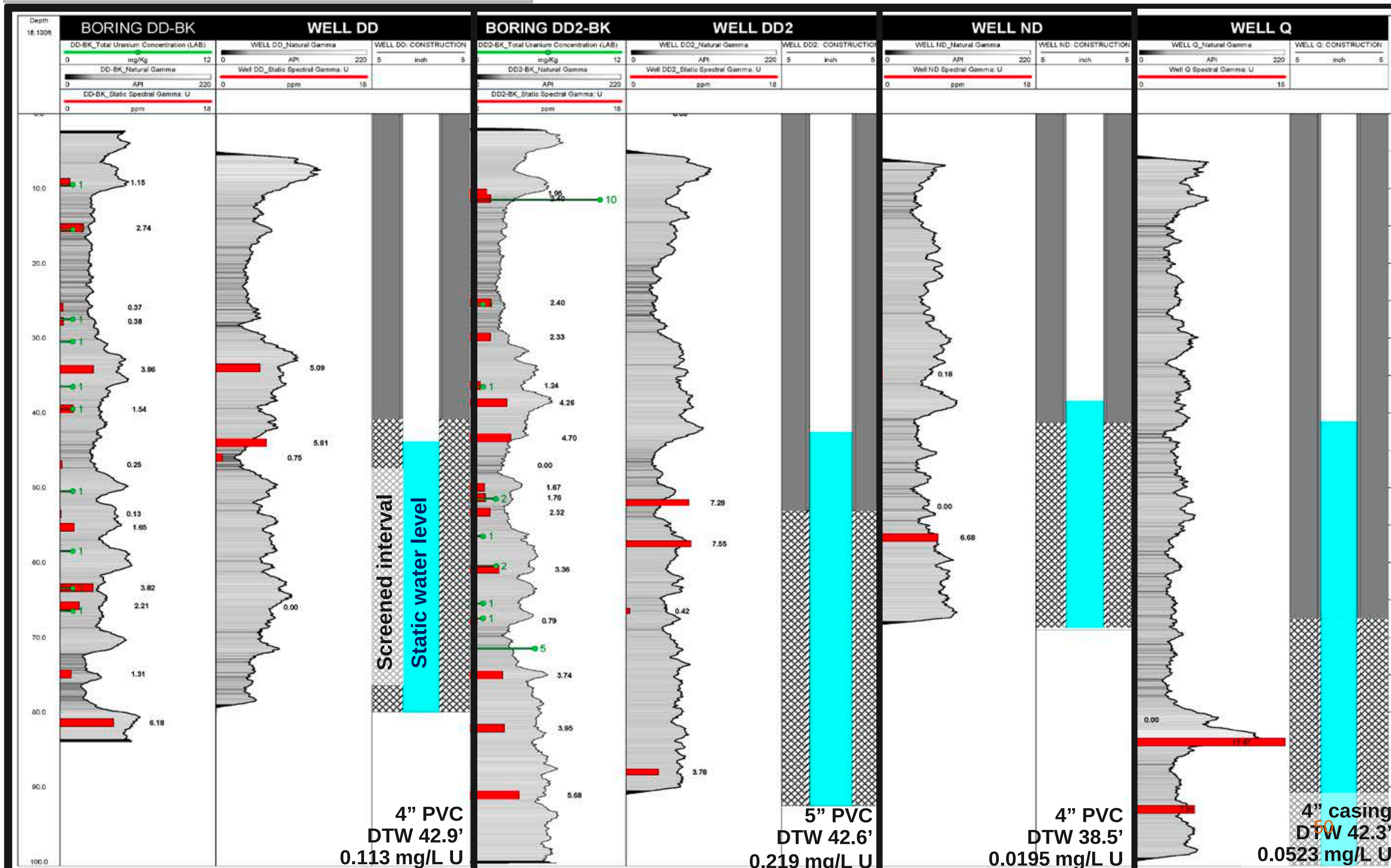
DD-BK and DD2-BK side-by-side correlations



Alluvial uranium and well construction

Natural gamma
6.18 Spectral gamma
1 Total uranium in soil borings (lab analysis)

Uranium in alluvium is preferentially in fine grained sediments and varies significantly by location



Note: further refinement of these plots is currently in progress and updated plots will be released in future presentations/publications.

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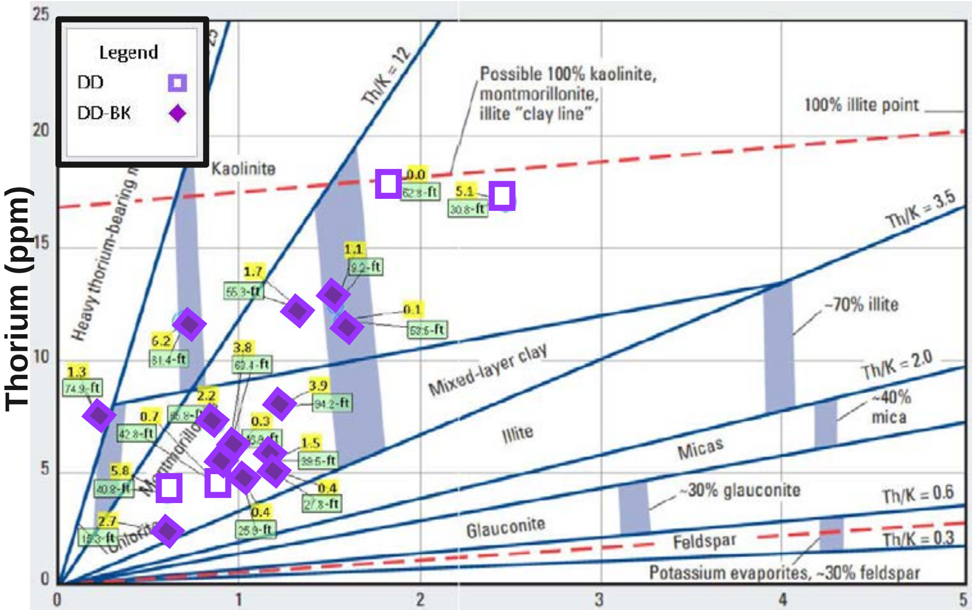
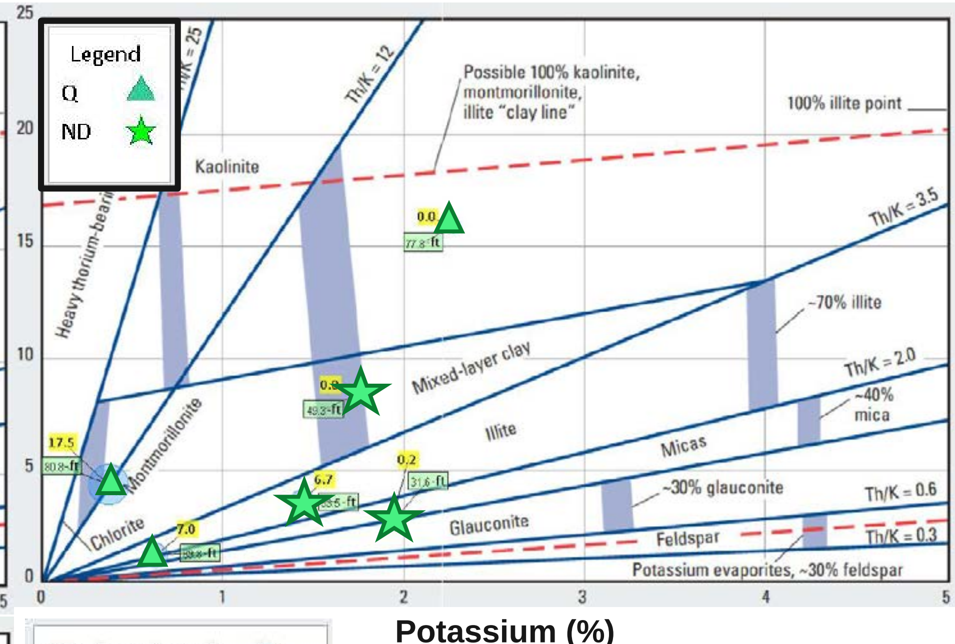
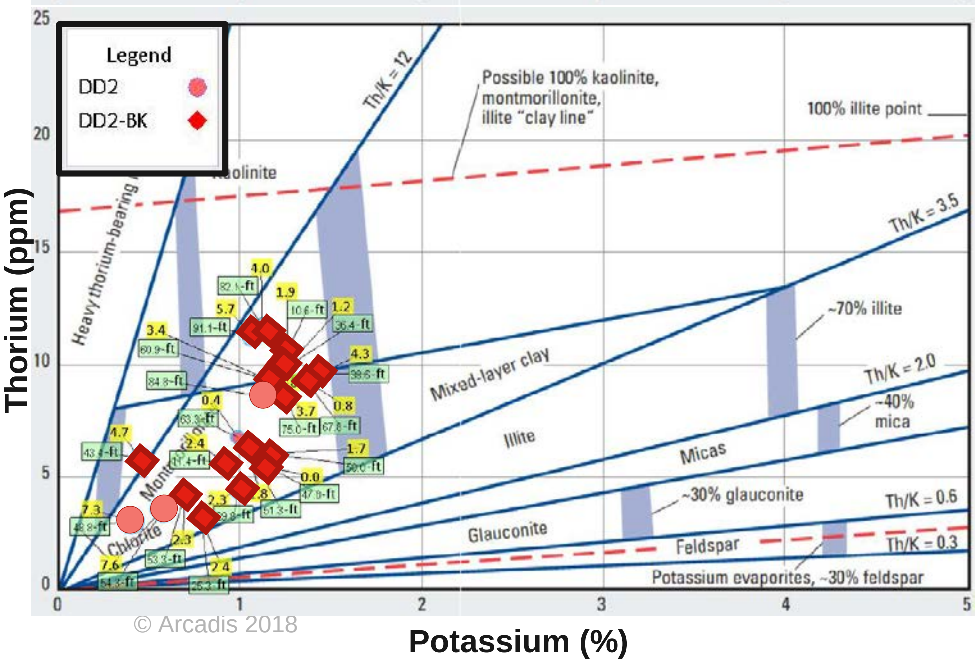




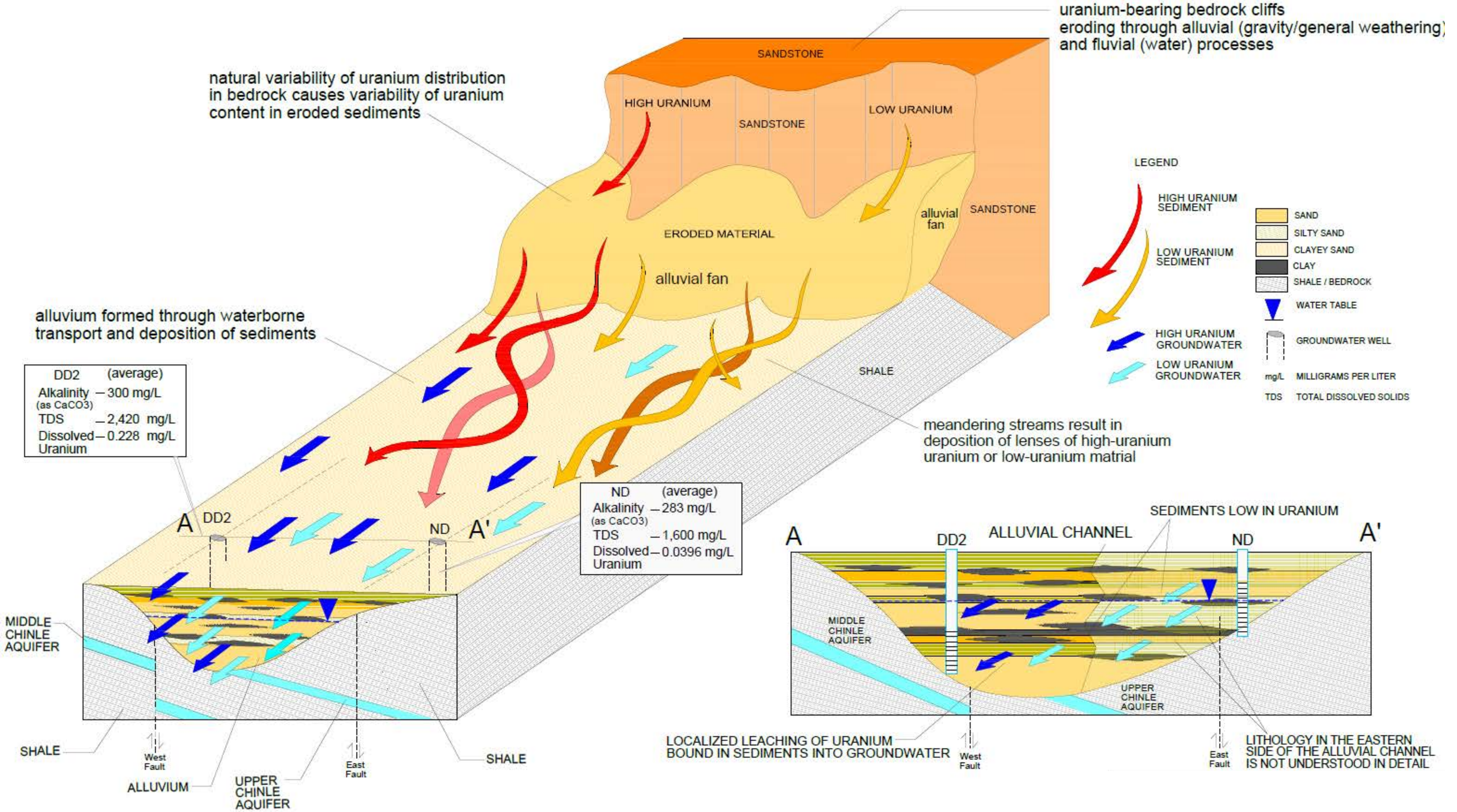


Uranium (ppm)

96.5 - Depth of Static Spectral Data in feet

12.0 - Uranium in ppm from static spectral data

Potassium-thorium plots support different alluvial sediment origin from east to west



Potassium-thorium plots support different alluvial sediment origin from east to west

White paper conceptual site model

- Source of alluvium = weathering and erosion of exposed bedrock formations over hundreds to thousands of years.
- Eroded sediments were transported/deposited by a meandering stream of varying velocity, resulting in alternating clay, silt, sand, and gravel layers.
- Concentration of uranium in the deposited sediments depends on both erosional and depositional environment:
  - High uranium bedrock units would weather into high uranium alluvium
  - Fine-gained sediments = higher uranium = high uranium alluvium
- Regional groundwater recharge varies across basin; groundwater along the east derived from lower-solute, low-uranium snowmelt from Mount Taylor.
- Localized dissolved uranium has leached from silt/clay-rich layers in the alluvial sequence in response to groundwater geochemistry (elevated alkalinity and TDS), resulting in groundwater containing variable natural uranium concentrations with depth and across the alluvial channel.

White paper conclusions

- Uranium present in soil minerals undergoes leaching in groundwater
- High uranium in the unsaturated zone shows that uranium is present in unaffected alluvial sedimentary material
- High uranium in samples protected from outside water by clay show that the uranium is not due to groundwater contact or surface water infiltration
- Mineralogy/lithology local to a well influences water chemistry
- Alluvial lithology and geologic cross section of the alluvial valley has been revised
- Upgradient alluvial background wells are not affected by LTP
- Upgradient background uranium and selenium concentrations in groundwater are highly variable